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(54) **ARTIFICIAL TURF FIBERS COMPRISING AGED POLYMERS AND A COMPATIBILIZER**

(57) The invention provides for a method of manufacturing an artificial turf fiber (710). The method comprises creating (502) a liquid polymer mixture (100, 200, 300, 400). The polymer mixture comprises a base polymer (102), plastic waste comprising one or more aged polymers (106, 302, 304), and a compatibilizer (104). The one or more aged polymers comprise an IM polymer (106, 302) that is not miscible with the base polymer. The

base polymer is an unaged polymer. The liquid polymer mixture is a multi-phase system. The compatibilizer emulsifies the IM polymer within the base polymer such that the IM polymer forms polymer beads surrounded by the compatibilizer within the base polymer. The method further comprises extruding (504) the polymer mixture into a monofilament (606) and fabricating the artificial turf fiber from one or more of the monofilaments.

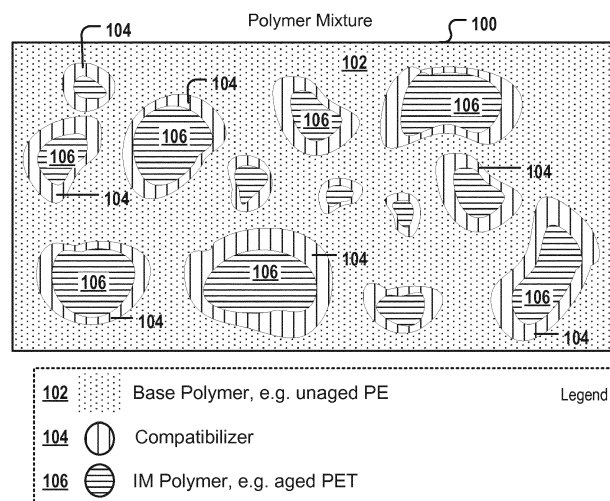


Fig. 1

Description

Field of the invention

[0001] The invention relates to artificial turf and the production of artificial turf; artificial turf is also referred to as synthetic turf. The invention further relates to the production of artificial turf fibers, and in particular to artificial turf fibers that are partially made of plastic waste.

Background and related art

[0002] Artificial turf (or artificial grass) is surface that is made up of fibers and used to replace real grass. The structure of the artificial turf is designed such that the artificial turf has an appearance that resembles grass. Typically, artificial turf is used as a surface for sports such as soccer, football, rugby, tennis, and golf, and for playing or exercise fields. Furthermore, artificial turf is frequently used for landscaping applications. An advantage of using artificial turf is that it eliminates the need to care for a grass playing or landscaping surface, such as having to perform regular mowing, scarifying, fertilizing, and watering (watering can be difficult due to logistics or regional restrictions for water usage). In other climatic zones, the regrowing of grass and reformation of a closed grass cover is slow compared with the rate of damaging the natural grass surface by playing and/or exercising on the field. Artificial turf may be manufactured using techniques for manufacturing carpets. For example, artificial turf fibers, which have the appearance of grass blades, may be tufted or otherwise integrated into a carrier. Often, artificial turf infill is placed between the artificial turf fibers. Artificial turf infill is a granular material that covers the lower portion of the artificial turf fibers.

[0003] Artificial turf fibers are typically made of polymers or polymer blends that have highly specific, defined mechanical properties. These properties ensure that the fibers can reliably recover from impact forces over a long period of time; have a desired optical appearance, elasticity, rigidity, and tensile strength; are easy to produce; and can be produced cost-effectively.

[0004] Today, more and more companies and sports clubs have become committed to sustainability. As a result, there have been several advances in using waste plastics for fabricating artificial turf fibers. For example, EP 2 161 374 B1 describes a method for producing an artificial turf for sports fields, garden design, and golf courses, wherein the artificial turf fibers consist for the most part of polyethylene terephthalate (PET) and/or polybutylene terephthalate (PBT) from waste materials. The fibers are produced substantially as multicomponent fibers having a core-sheath configuration, whereby the sheath plastic consists substantially of PET or PBT from waste materials or virgin PET or PBT, and whereby the core consists substantially of PET and/or PBT from waste materials.

[0005] A problem associated with many approaches

of using plastic waste in the production of artificial turf fibers is that the available plastic waste is a "post consumer" waste, i.e., is a heterogeneous mixture of different types of plastics. Typically, the exact composition of post-consumer plastic waste is not known and varies over time. Hence, the mechanical and chemical properties of postconsumer plastic waste are typically not known and vary unpredictably. In many cases, this excludes the use of plastic waste to produce a new, high-quality artificial turf fiber. Sometimes, plastic waste is preprocessed in a complex manner, e.g., filtered, sorted, heated, or crystallized, in order to separate different types of polymers from each other. However, this preprocessing of waste is often highly time-consuming and expensive. What's more, frequently, different plastic types cannot be separated at all or cannot be separated to different polymer fractions that are sufficiently pure for being usable as an educt in an artificial turf fiber production process. Therefore, artificial turf fibers made from recycled plastic waste often require the plastic waste to be postindustrial waste rather than postconsumer waste, or require a complex preprocessing of the postconsumer waste in order to separate the plastic waste into the different types of polymers to be used for manufacturing a new artificial turf fiber from old plastic waste.

Summary

[0006] The invention provides for an artificial turf fiber and a method of manufacturing an artificial turf fiber as specified in the independent claims. Embodiments are given in the dependent claims. Embodiments and examples described herein can freely be combined with each other if they are not mutually exclusive.

[0007] In one aspect, the invention provides for a method of manufacturing an artificial turf fiber. The method comprises providing plastic waste comprising one or more aged polymers; providing a base polymer. The base polymer is an unaged polymer; heating and mixing the plastic waste and the base polymer and a compatibilizer for creating a liquid polymer mixture, wherein the one or more aged polymers comprise an immiscible (IM) polymer that is not miscible with the base polymer, wherein the liquid polymer mixture is a multi-phase system and wherein the compatibilizer emulsifies the IM polymer within the base polymer phase such that the IM polymer forms polymer beads surrounded by the compatibilizer within the base polymer phase; extruding the liquid polymer mixture into a monofilament; and fabricating the artificial turf fiber from one or more of the monofilaments.

[0008] For example, the providing of the plastic waste may comprise pre-processing, e.g. shredding, the plastic waste and adding it to a particular container, e.g. a container in an extrusion machine. The providing of the base polymer can comprise, for example, adding base polymer granules to said container.

[0009] The multiphase system may comprise a base polymer phase that comprises or basically consists of

the base polymer or a base polymer blend, a compatibilizer phase that comprises or basically consists of the compatibilizer, and at least one further phase consisting of the inner volume of beads comprising the same type of polymers or polymer blends. For example, a further phase could consist of droplets of aged PA emulsified by the compatibilizer in the base polymer phase.

[0010] Said features may be advantageous, as they allow using heterogeneous plastic waste of unknown composition directly, without complex preprocessing for separating the plastic waste into different components and polymer types. Adding a compatibilizer to the polymer mixture may ensure that even in cases when the aged polymers should comprise many different types of polymers wherein all or some of them are not mixable with the base polymer, these immiscible polymers ("IM polymers") will not result in a significant deterioration of the properties of the artificial turf fiber. This is because the base polymer of the fiber is made from one or more unaged polymers and, hence, has clearly defined and desired mechanical and chemical properties. In cases where the aged polymers should comprise one or more polymers that are immiscible with the base polymer phase, the compatibilizer will emulsify the IM polymer(s), thereby ensuring that any IM polymer is homogeneously dispersed within the base polymer phase. As the IM polymer beads are encapsulated by the compatibilizer, delamination at the contact zone of the base polymer and the IM polymer(s) is prevented.

[0011] Embodiments of the invention may allow using basically any kind of homogeneous as well as heterogeneous plastic waste for manufacturing an artificial turf fiber of clearly defined mechanical and optical properties. The resulting artificial turf fiber has identical or highly similar properties like an artificial turf fiber that is completely made of unaged polymer material.

[0012] The issue of recycling plastic waste lies in separating all the materials that are used to create new products from the recycled polymers so that the product reproducibly and predictably has the desired mechanical or chemical properties. For that reason, it was historically much easier - and less expensive - to simply toss plastic waste into a landfill or "recycle" plastic waste by incineration. However, applicant has observed that using a compatibilizer may allow the creation of a polymer mixture and a respective monofilament and artificial turf fiber that comprise up to 40 % by weight plastic waste without significantly reducing the quality of the artificial turf fiber. The plastic waste can be homogeneous or heterogeneous plastic waste. Hence, embodiments of the invention may allow recycling rather than down-cycling or incinerating large amounts of heterogeneous postindustrial as well as postconsumer plastic waste, and may allow creating artificial turf fibers from recycled polymer material that are identical or highly similar to "conventional" artificial turf fibers made from virgin polymers. The fibers made partially from aged polymers are typically not significantly more expensive than their conventional fiber

counterparts.

[0013] For example, the base polymer used for manufacturing a conventional artificial turf fiber could be an unaged, apolar polymer, e.g., polyethylene (PE). If one tries to substitute a fraction of the PE with recycled heterogeneous polymer mixtures, or even with recycled PE alone, there is almost always the problem that the aged polymers and the waste PE contain traces of other polymers that do not mix with PE. For example, apolar polymers, e.g., polyamide (PA) or polyethylene-terephthalate (PET), do not mix with and form a blend with PE when heated. Hence, an artificial turf fiber made of a mixture of a base polymer and heterogeneous plastic waste that lacks a compatibilizer will have undesired mechanical properties, because the one or more IM polymers that are typically contained in the plastic waste in a range of 0.1 to 20% by weight of the plastic waste tend to form large, separate phases. As a consequence, parts of the resulting monofilament will easily delaminate at the contact zone of the base polymer phase and the IM polymer phase. To the contrary, the compatibilizer may emulsify the IM polymer(s) (alone or as a component of a blend with an unaged thread-polymer that is miscible with said IM polymer) in the form of beadlike structures, e.g., small droplets, within the base polymer phase; may prevent the separation of two large phases; and may prevent the delamination of the monofilaments created by extruding the polymer mixture.

[0014] According to embodiments, the base polymer is polyethylene or polypropylene or a mixture thereof. Using PE may be advantageous, as PE provides for an elastic artificial turf fiber that has a smooth surface that protects the skin of the players from injuries.

[0015] According to embodiments, the IM polymer is polypropylene (PP), polyamide (PA), polyethylene-terephthalate (PET), polyethylene (PE), polybutylene terephthalate (PBT) or a mixture of two or more of these polymer types.

[0016] PP is a thermoplastic polymer widely used in many different applications, including automotive components, containers, plastic parts, packaging and labeling, loudspeakers, stationery, and textiles. PP is rugged and resistant to different chemical solvents, acids, and bases. It is also used for producing low-cost artificial turf fibers that are particularly chemically robust.

[0017] PET is a plastic often used for manufacturing food-grade plastic, e.g., plastic bottles. It is also used for producing "bundling fibers," i.e., a special type of fiber used for bundling two or more monofilaments into an artificial turf fiber. PET is particularly mechanically robust.

[0018] PA is a macromolecule with repeating units linked by amide bonds. Artificially made polyamides can be made through step-growth polymerization or solid-phase synthesis, yielding materials such as nylons, aramids, and sodium poly (aspartate). Synthetic polyamides are commonly used in textiles, automotive applications, carpets, and sportswear due to their high durability and strength. PA is also used for manufacturing artificial turf

fibers.

[0019] Some of the above-mentioned materials, e.g., PA and PET, are not miscible with PE when heated together, e.g., in an extruder. As a consequence, plastic waste that consists of, comprises, or is contaminated with a PA or PET polymer could previously not be used for manufacturing artificial turf fibers that have the same desired physical and chemical properties as conventional artificial turf fibers made from virgin polymers. By adding a compatibilizer, it is ensured that plastic waste consisting of, comprising, or contaminated with PA, PET, or PBT can be used for generating high-quality artificial turf fibers. Hence, large amounts of heterogeneous postconsumer plastic waste may now be fully recycled and may be used for manufacturing new artificial turf fibers.

[0020] According to embodiments, the IM polymer is polar. In addition, or alternatively, the base polymer is apolar. For example, PE is an apolar polymer. PA, PET, and PBT are polar polymers.

[0021] According to embodiments, the polymer mixture comprises 1 to 40 percent by weight the plastic waste. In some embodiments, the polymer mixture comprises at least 10 percent by weight the plastic waste. In some embodiments, the polymer mixture comprises at least 20 percent by weight the plastic waste. In some embodiments, the polymer mixture comprises at least 30 percent by weight the plastic waste. Preferably, the polymer mixture comprises less than 41 percent by weight the plastic waste, e.g., 20 to 30 percent by weight the plastic waste.

[0022] Typically, the plastic waste comprises 0.1 to 30 % by weight the IM polymer or a combination of two or more different IM polymers, which are all immiscible with the base polymer phase (and are immiscible with the base polymer) and may be miscible or immiscible with each other.

[0023] Typically, the plastic waste consists of the one or more aged polymers and some additives like pigments, flame retardants, fillers, or the like. Usually, only about 5% or less, e.g. less than 1% by weight of the plastic waste consists of the additives, the rest consists of the one or more aged polymers. Hence, in many embodiments, the plastic waste basically consists of the one or more aged polymers. Accordingly, the polymer mixture can comprise 1 to 40 percent by weight the one or more aged polymers. In some embodiments, the polymer mixture comprises at least 10 percent by weight the one or more aged polymers. In some embodiments, the polymer mixture comprises at least 20 percent by weight the one or more aged polymers. In some embodiments, the polymer mixture comprises at least 30 percent by weight the one or more aged polymers. Preferably, the polymer mixture comprises less than 41 percent by weight the one or more aged polymers, e.g., 20 to 30 percent by weight the one or more aged polymers. Typically, the one or more aged polymers comprise 0.1 to 30 % by weight the IM polymer or a combination of two or more different IM polymers, which are all immiscible with the base pol-

ymers and may be miscible or immiscible with each other.

[0024] According to embodiments, the polymer mixture comprises a thread-polymer. The compatibilizer emulsifies the thread-polymer or a blend of the thread-polymer and the IM polymer within the base polymer phase such that the thread-polymer or the blend forms polymer beads surrounded by the compatibilizer within the base polymer phase.

[0025] The base polymer phase is the phase of the liquid polymer mixture that comprises or basically consists of the base polymer or of a blend of the base polymer with one or more aged polymers which are miscible with the base polymer. When the extruded polymer mixture solidifies, the base polymer phase solidifies into a "base polymer mass" that consists of the components of the base polymer phase, i.e., of the base polymer or of the above mentioned base polymer blend.

[0026] According to embodiments, the method further comprises quenching the extruded monofilament, reheating the quenched monofilament, and stretching the reheated monofilament to deform the polymer beads into threadlike regions. The artificial turf fiber is fabricated from one or more stretched monofilaments. Depending on the embodiments, the beads may comprise the IM polymer or a blend of two or more IM polymers (miscible with each other but not with the base polymer), or the thread-polymer or a blend of the thread-polymer with the IM polymer or a mixture of two or more of these types of beads.

[0027] For example, the polymer mixture can be heated during the extrusion process and portions of the thread-polymer and also the base polymer may have a more amorphous structure or a more crystalline structure in various regions. Stretching the polymer beads into the threadlike regions may cause an increase in the size of the crystalline portions relative to the amorphous portions in the thread-polymer. This may lead, for instance, to the thread-polymer becoming more rigid than when it has an amorphous structure. This may lead to an artificial turf with more rigidity and ability to spring back when pressed down. The stretching of the monofilament may also cause - in some cases - the second polymer or other additional polymers to have a larger portion of their structure become more crystalline.

[0028] In a specific example of this, the thread-polymer could be polyamide and the base polymer could be polyethylene. Stretching the polyamide will cause an increase in the crystalline regions, making the polyamide stiffer. This is also true for other plastic polymers.

[0029] The thread-polymer can be a single polymer or can be a polymer blend. The thread-polymer can basically consist of an unaged polymer. The beads formed by the compatibilizer and the thread-polymer can basically consist of the thread-polymer or of a blend of the thread-polymer with one or more IM polymers. The thread-polymer is a polymer and the beads comprising or consisting of the thread-polymer are immiscible with the base polymer (and, accordingly, immiscible with the

base polymer phase).

[0030] Said features may have the advantage that the extrusion of an emulsion of a liquid polymer mixture generated by the compatibilizer will result in the fabrication of a monofilament that has a particular high rigidity. This is because the beads are deformed during the extrusion process into threadlike regions that are oriented along the direction of the extrusion process. If the resulting monofilament is bent down, e.g., by the ball or by the foot of a player, the threadlike regions generated by the thread-polymer ensure that the fiber will soon recover and "re-erect" from the impact. The compatibilizer may ensure that the thread-polymer and the base polymer will not delaminate.

[0031] A further advantage may possibly be that the threadlike regions are concentrated in a central region of the monofilament during the extrusion process. This leads to a concentration of the more rigid material in the center of the monofilament and a larger amount of softer plastic on the exterior or outer region of the monofilament. This may further lead to an artificial turf fiber with more grasslike properties.

[0032] Yet another advantage may be that the artificial turf fibers have improved long-term elasticity. This may require reduced maintenance of the artificial turf and less brushing of the fibers, because they more naturally regain their shape and stand up after use or being trampled.

[0033] According to embodiments, the polymer beads comprise crystalline portions and amorphous portions. The extruded monofilament may be stretched before it is used for fabricating the artificial turf fiber. The stretching of the polymer beads into threadlike regions causes an increase in the size of the crystalline portions relative to the amorphous portions. This may increase the capability of the artificial turf fiber to regain its shape and stand up after use or being trampled.

[0034] The threadlike regions are embedded within the base polymer phase. It is therefore impossible for them to delaminate. The use of the thread-polymer and the base polymer enables the properties of the artificial turf fiber to be tailored. For instance, a softer plastic may be used for the base polymer to give the artificial turf a more natural grasslike and softer feel. A more rigid plastic may be used for the thread-polymer or other immiscible polymers to give the artificial turf more resilience and stability as well as the ability to spring back after being stepped on or pressed down. Artificial turf fibers with threadlike regions as such are known, e.g., from WO 2015/144223. However, applicant has surprisingly observed that aged, used plastic is typically more rigid than unaged plastic is. Hence, the IM polymer can be used for generating threadlike regions instead of or in addition to the threadlike regions generated by an unaged polar polymer that was already hitherto used as a thread-polymer for creating threadlike regions. As the amount of the IM polymer in a piece of old, used plastic is typically not known, an extra thread-polymer made that is unaged, e.g., new PA, may be added to the polymer mixture to ensure a minimum

amount of threadlike regions will be contained in the extruded monofilament. This may ensure a minimum degree of rigidity and resilience of the monofilament and the fiber manufactured therefrom.

[0035] The term "polymer bead" (or "beads") may refer to a localized region, such as a droplet, of a polymer that is immiscible in the base polymer. The polymer beads may in some instances be round, spherical, or oval-shaped, but they may also be irregularly shaped. In some instances, the polymer bead will typically have a size of approximately 0.1 to 3 micrometers, preferably 1 to 2 micrometers in diameter. In other examples, the polymer beads will be larger. They may, for instance, have a diameter of a maximum of 50 micrometers.

[0036] According to embodiments, the thread-polymer consists of or basically consists of the IM polymer.

[0037] The expression "A basically consists of B" as used herein means that at least 90%, typically at least 95% of the substance composition A consists of substance B. The substance composition may in addition comprise one or more additives, such as pigments, light stabilizers, biocides, flame retardants, and the like.

[0038] In some examples, the plastic waste used for manufacturing the artificial turf fibers comprises a sufficient amount of aged polymer that is immiscible with the base polymer or may basically consist of this aged polymer, whereby the IM polymer is preferably more rigid than the base polymer. For example, the aged polymer(s) may comprise about 20 to 50 % PA. In this case, depending on the amount of the plastic waste added to the polymer mixture, the liquid polymer mixture will comprise an IM polymer that is immiscible with the base polymer, is more rigid than the base polymer, and is therefore particularly suited for being used - alone or as a blend with other new or old polymers - to form the beads that are extruded and optionally stretched into threadlike regions. This is achieved by the compatibilizer emulsifying any immiscible IM polymer, in particular polar IM polymer, in the form of beadlike structures within the base polymer phase.

[0039] According to other embodiments, the thread-polymer is an unaged polymer and forms a blend with the IM polymer. For example, the liquid polymer mixture is created by adding a further, unaged polymer to the polymer mixture, whereby the further polymer is more rigid than the base polymer. For example, the further polymer can be an unaged PA. The unaged PA and the old PA contained in the plastic waste that was used for providing the aged polymers may intermix with each other and form a polymer blend. The polymer blend comprises the "new thread-polymer" and the "old IM polymer" and is emulsified by the compatibilizer.

[0040] Additionally, adding the further, unaged polymer may be beneficial, as it may ensure that beads and threadlike regions are formed even in cases when the heterogeneous plastic waste that used for creating the polymer mixture should not comprise (sufficient amounts of) a polymer type that is immiscible with the base poly-

mer and/or should not comprise a polymer type that is more rigid than the base polymer. In this case, the unaged thread-polymer ensures that at least a minimum number of the threadlike regions are formed. Hence, adding an unaged PA or another unaged polymer that is preferably polar and more rigid than the apolar base polymer (e.g., PE or PP - or a mixture thereof) may ensure that irrespective of the

[0041] (typically unknown) composition of the aged polymer used for manufacturing the artificial turf fiber, a minimum amount of threadlike regions will be contained in the extruded monofilament, thereby ensuring that the manufactured artificial turf fiber will regain its shape and stand up after use or being trampled.

[0042] According to embodiments, the thread-polymer is a polar polymer, in particular polyamide or polyethylene-terephthalate, or a mixture of polar polymers, e.g., a blend of polar polymers. In some embodiments, the thread-polymer is adapted to form a blend with one or more polar IM polymer(s) that are emulsified by the compatibilizers.

[0043] In some embodiments, the thread-polymer and the beadlike structures basically consist of unaged PA. In other embodiments, the thread-polymer and the beadlike structures in the liquid mixture basically consist of unaged PET.

[0044] In some further embodiments, the beadlike structures basically consist of a blend of unaged PA used as the thread-polymer and of old PA derived from plastic waste. In other embodiments, the beadlike structures basically consist of a blend of unaged PET used as the thread-polymer and of old PET derived from plastic waste.

[0045] In some embodiments, the thread-polymer is a new, polar polymer, in particular polyamide or polyethylene-terephthalate. Alternatively, the thread-polymer is a blend of unaged polar polymers having basically identical melting temperatures.

[0046] In some examples, the extruded (and optionally stretched) monofilament may be used directly as the artificial turf fiber. For example, the monofilament could be extruded as a tape or other shape. In other examples, the artificial turf fiber may be a bundle or group of several stretched monofilament fibers that are generally cabled, twisted, or bundled together. In some cases, the bundle is rewound with a so-called rewinding yarn, which keeps the yarn bundle together and makes it ready for the later tufting or weaving process. The monofilaments may, for instance, have a diameter of 50 to 600 micrometers in size. The yarn weight may typically reach 50 to 3,000 dtex.

[0047] According to embodiments, the threadlike regions have a diameter of less than 50 micrometers.

[0048] According to embodiments, the threadlike regions have a diameter of less than 10 micrometers.

[0049] According to embodiments, the threadlike regions have a diameter of between 1 and 3 micrometers.

[0050] According to embodiments, the artificial turf fib-

er extends a predetermined length beyond the artificial turf backing, and therein, threadlike regions have a length of less than one-half of the predetermined length.

[0051] According to embodiments, the threadlike regions have a length of less than 2 mm.

[0052] According to embodiments, the polymer mixture comprises 1 to 40, in particular 5 to 30 %, in particular 5 to 15 % by weight the thread-polymer.

[0053] According to embodiments, the creation of the polymer mixture comprises the steps of: forming a first mixture by mixing shredded and optionally agglomerated plastic waste comprising one or more IM polymers with the compatibilizer; heating the first mixture; extruding the first mixture; granulating the extruded first mixture; mixing the granulated first mixture with the base polymer; and heating the granulated first mixture with the base polymer to form the (final) polymer mixture. The heating is performed such that preferably all polymers contained in the (final) polymer mixture melt. This allows the intermixing of those aged polymers with the base polymer which are miscible with the base polymer, if any. The resulting base polymer phase may basically consist of the base polymer or may consist of a blend of the base polymer and one or more of the ones of the waste polymers which are miscible with the unaged base polymer. The IM polymers will not mix with the base polymer but will rather form the beads in a separate phase within the multiphase liquid polymer mixture.

[0054] This particular method of creating the polymer mixture may be advantageous because it enables very precise control over how the aged polymers and in particular the IM polymer(s) and compatibilizer are distributed within the base polymer phase. For instance, the size or shape of the extruded first mixture may have an impact on the size of IM polymer beads in the polymer mixture.

[0055] In the aforementioned method of creating the polymer mixture, for instance, a so-called one-screw extrusion method may be used. As an alternative to this, the polymer mixture may also be created by putting all the components that make it up together at once. For instance, the IM polymer, the base polymer, and the compatibilizer could be all added at the same time. Other ingredients such as additional polymers or other additives could also be put together at the same time. The amount of mixing of the polymer mixture could then be increased, for instance, by using a two-screw feed for the extrusion. In this case, the desired distribution of the polymer beads can be achieved by using the proper rate or amount of mixing.

[0056] In some examples, the step of forming the first mixture by mixing the IM polymer with the compatibilizer may optionally comprise forming the first mixture by mixing the IM polymer, an unaged polymer acting as the thread-polymer, and the compatibilizer.

[0057] According to some embodiments, the polymer mixture is at least a four-phase system. The polymer mixture comprises at least two different types of IM polymers,

which are neither miscible with each other nor with the base polymer. Each of the at least two different types of IM polymers is emulsified by the compatibilizer within the base polymer phase.

[0058] According to embodiments, the plastic waste used for providing the polymer mixture further comprises a further aged polymer that is miscible with the base polymer and forms a blend with the base polymer in the liquid polymer mixture. For example, the further aged polymer can be an aged, used PE. The aged PE may be deprived of light stabilizers and may comprise polymer molecules whose average main chain length is shorter than that of the base polymer (which can be unaged PE). Nevertheless, the old PE may still be miscible with the new PE. Embodiments of the invention may be advantageous, as some fractions of a heterogeneous aged polymer mixture may be mixable with the base polymer and may form a base polymer blend while other fractions of the aged polymer that are not miscible with the base polymer are emulsified by the compatibilizer within the base polymer phase, i.e., within the base polymer or the base polymer blend. Hence, any kind of polar or apolar aged polymer mixture may be added to the polymer mixture. The use of an apolar base polymer in combination with a compatibilizer that mediates the contact of an apolar

base polymer and a polar IM polymer may ensure that any kind of plastic waste can be used for producing a new artificial turf fiber that will not delaminate at the contact zones of the different, IM polymers.

[0059] According to embodiments, the compatibilizer is any one of the following: a maleic acid grafted on polyethylene or polyamide; a maleic anhydride grafted on a free-radical-initiated graft copolymer of polyethylene; SEBS, EVA, EPD, or polypropylene with an unsaturated acid or its anhydride, such as maleic acid, glycidyl methacrylate, or ricinoloazoline maleinate; a graft copolymer of SEBS with glycidyl methacrylate; a graft copolymer of EVA with mercaptoacetic acid and maleic anhydride; a graft copolymer of EPDM (ethylene propylene diene monomer rubber) with maleic anhydride; a graft copolymer of polypropylene with maleic anhydride; a polyolefin-graft-polyamidopolyethylene or polyamide; and a polyacrylic acid-type compatibilizer.

[0060] According to embodiments, about 5% to 10% by weight of the polymer mixture consist of the compatibilizer.

[0061] According to embodiments, the polymer mixture comprises 60 to 99 percent by weight the base polymer.

[0062] According to embodiments, the polymer mixture further comprises any one of the following: a wax, a dulling agent, a UV stabilizer, a flame retardant, an anti-oxidant, a pigment, and combinations thereof.

[0063] According to embodiments, creating the artificial turf fiber comprises forming the stretched monofilament into a yarn.

[0064] According to embodiments, creating the artificial turf fiber can comprise weaving, spinning, twisting,

rewinding, and/or bundling the stretched monofilament into the artificial turf fiber.

[0065] According to embodiments, incorporating the artificial turf fiber into the carrier comprises tufting the artificial turf fiber into the carrier. Optionally, a liquid backing, e.g., a liquid latex or polyurethane mixture, is added on the lower side of the carrier from which the U-shaped portions of the tufted fibers emanate. The liquid backing incorporates the U-shaped fiber portions and firmly fixes the fibers in the carrier when the liquid backing hardens. The hardening can be a drying process and/or a chemical polymerization process or any other process that transforms a liquid into a solid backing.

[0066] According to embodiments, incorporating the artificial turf fiber into the carrier comprises weaving the artificial turf fiber into the carrier.

[0067] The carrier can be, for example, a textile mesh.

[0068] According to embodiments the IM polymer is a blend of two or more different aged polymers.

[0069] According to embodiments, the composition of the two or more different aged polymers that may comprise one or more IM polymers is not known and/or varies over time. For example, the composition of the IM polymer(s) may vary between different product batches of the artificial turf fiber. After 20 years of use of an artificial turf field, there is often no information available regarding the detailed composition of the artificial turf system.

[0070] According to embodiments, the polymer mixture comprises 60 to 99 percent by weight the base polymer.

[0071] According to embodiments, the plastic waste comprises a mixture of two or more different types of aged polymers.

[0072] According to embodiments, the plastic waste is shredded plastic waste of heterogeneous origin, in particular shredded postconsumer plastic waste.

[0073] The one or more aged polymers contained in the plastic waste can be an unknown composition of a plurality of different types of aged polymers. The heterogeneous waste plastic may comprise plastics made of many different types of polyolefine polymers; may comprise plastics with different degrees of oxidation and photo bleaching; may comprise an unknown mixture of polar and apolar polymers; and/or may comprise a mixture of plastics having strongly different melting temperatures. Any type of postconsumer plastic waste is typically highly heterogeneous. Often, the composition of the plastic waste varies significantly over time, depending on the source from where the plastic waste is derived. Typically, the plastic waste is a shredded, cut, crushed, minced, grinded or otherwise dismembered mixture of plastic waste derived from one or more different sources.

[0074] Embodiments of the invention may be advantageous, as it may be possible to use also heterogeneous waste plastic of unknown and varying composition for producing new artificial turf fibers.

[0075] According to embodiments, the plastic waste consists of or comprises ocean plastics.

[0076] "Ocean plastics," as used herein, are plastics collected from the ocean. Typically, ocean plastics are a highly heterogeneous, strongly oxidized plastic mass. This mass can comprise basically any type of plastic product and its respective polymers. For example, ocean plastics can comprise plastic bags, plastic straws, old car tires, discarded fishing nets, plastic bottles, and/or other types of plastic waste.

[0077] According to embodiments, the plastic waste comprises used artificial turf fibers, in particular a mixture of different types of used artificial turf fibers.

[0078] Current artificial turf systems are often highly complex products that may comprise a large number of different fiber types, and each fiber type may consist of one or more different polymer types. For example, an artificial turf could comprise face yarn fiber, which faithfully reproduces the look and feel of natural grass. These face yarn fibers could consist of a combination of PE and PA. In addition, the artificial turf could comprise thatch yarn fibers made of PP or a PP-based blend. In addition, or alternatively, the artificial turf may comprise a bundle fiber that is used for bundling together two or more monofilaments. The bundle fiber may be a PET fiber. It is not technically possible at this time to separate these different types of fibers, let alone the components of fibers consisting of a polymer blend, into the different fiber types or the individual, pure polymer types. Typically, if an old artificial turf field is de-installed after a use time of 10, 20, or 30 years, the detailed composition of the field and its fibers is not known, and even if it would be known, it would not be feasible to separate the different fibers and polymers contained in old artificial turf.

[0079] Embodiments of the invention allow manufacturing high-quality artificial turf fibers that comprise significant portions of heterogeneous IM polymers or polymer mixtures derived from worn-out, used artificial turfs. This may be advantageous, as artificial turf fields typically exhibit wear after five to 15 years. Mechanical damage from use and exposure to UV radiation, thermal cycling, interactions with chemicals, and various environmental conditions generate wear on artificial turf. It is therefore beneficial, both economically and environmentally, to use an existing worn artificial turf as a base for manufacturing a new artificial turf system. The manufacturing of the artificial turf fiber is preferably free of any preprocessing step for separating the different polymers contained in the aged polymer used for providing the IM polymer(s) and/or is free of any step of converting the aged polymer materials into pure raw materials.

[0080] For example, the mixture of different types of artificial turf fibers can be used as the source of the one or more aged polymers, including the one or more IM polymers. The mixture of the different artificial turf fibers can comprise face yarn fibers, thatch yarn fibers, and/or bundling fibers. The face yarn fibers can be made, for example, from PE, PP, or PE/PA fibers. The thatch yarn fibers can be made of PA or PE/PA. The bundling fibers can be made of PET. In one example, the mixture of

different types of artificial turf fibers used as the aged polymer material from which the one or more aged polymers are derived comprises 1 to 8 % PET, in particular 2 to 5 % PET. The rest can be PE or a combination of at least 70% PE in combination with PA and/or PP.

[0081] In some embodiments, the waste plastic material is shredded and optionally aggregated and then transferred together with the compatibilizer into an extruder. The waste plastic material is preferably not processed in order to separate different types of polymers from each other. This may accelerate the process of fiber manufacturing and may reduce costs.

[0082] According to embodiments, the extrusion is a co-extrusion of at least a first polymer mass and a second polymer mass. The co-extrusion comprises extruding the first and the second polymer mass together through a common extrusion path such that the first polymer mass is concentrically surrounded by the second polymer mass, and such that the two polymer masses are in contact while being co-extruded through the common extrusion path. The first polymer mass is the polymer mixture created in a method as described herein for embodiments of the invention. The second polymer mass is an unaged cladding polymer. The cladding polymer is miscible with the base polymer.

[0083] According to embodiments, the cladding polymer is polyethylene.

[0084] According to embodiments, the IM polymer comprises less than 0.3% by its weight a light stabilizer, e.g., Hindered amine light stabilizers (HALS). This amount of light stabilizer is significantly below the amount range of most types of unaged polymers used for artificial turf fiber production (typically about 0.7 to 0.9 % by weight). For example, HALS light stabilizers tend to migrate and leave artificial turf fibers after several years. According to embodiments, the totality of aged polymers used for creating the polymer mixture comprises less than 0.3% by weight the light stabilizer, e.g., HALS.

[0085] In addition, or alternatively, the IM polymer has a melt flow index of 5.0 to 7.0 g/10 min. This is because UV light introduces breaks in the main chain and the side chains of a polymer that is exposed to the sunlight. Hence, IM polymers (as well as the other aged polymers, if any, contained in the plastic waste that was added to the polymer mixture to be used for fabricating the artificial turf fiber) typically represent polymer types with deteriorated properties and shorter chain lengths. If a polymer is damaged - for example by UV radiation, heat, or exposure to certain chemicals to such an extent that chain degradation begins, its melt viscosity is reduced and the melt volume flow rate increases. Hence, the concentration of light stabilizers and/or the melt flow index and also other features like the degree of oxidation can be used as indicators of the age of a polymer.

[0086] As the IM polymer is embedded and integrated within the base polymer phase that comprises or basically consists of the unaged base polymer, the aging-induced deterioration has basically no effect on the qual-

ity of the manufactured artificial turf fiber. Typically, the base polymer will comprise light stabilizers, e.g., HALS, in an amount that is sufficient to protect the artificial turf fiber from UV radiation for the following years, and will comprise a polymer having a chain length and other physical properties as desired or necessary in view of the intended use of the artificial turf fiber (soccer, rugby, golf, or landscaping appliance).

[0087] In a further aspect, the invention relates to a method of manufacturing artificial turf. The method comprises incorporating a plurality of artificial turf fibers manufactured according to any method described herein for embodiments of the invention into a carrier.

[0088] In a further aspect, the invention relates to an artificial turf fiber manufactured according to the method of any one of the embodiments and examples described herein.

[0089] In a further aspect, the invention relates to an artificial turf fiber comprising at least one monofilament. Each of the at least one monofilament comprises a base polymer mass and threadlike regions embedded within the base polymer mass. The base polymer mass comprises or consists of a base polymer. The base polymer is an unaged polymer. For example, the base polymer mass corresponds to the base polymer phase of the liquid polymer mixture and may basically consist of the base polymer or of a blend of the base polymer with one or more aged polymers that are mixable with the base polymer. The threadlike regions comprise one or more aged IM polymers. The IM polymers are aged polymers that are not miscible with the base polymer in liquid state. The monofilament further comprises a compatibilizer that embeds and surrounds the threadlike regions within the base polymer mass. The IM polymer and the aged polymers that are miscible with the base polymer, if any, are derived from plastic waste.

[0090] The plastic waste can be a heterogeneous plastic waste as described herein for embodiments and examples of the invention.

[0091] In a further aspect, the invention relates to an artificial turf comprising a textile carrier and an artificial turf fiber as described herein for embodiments of the invention. The fiber is incorporated into the carrier. The fiber can optionally be further fixed in the carrier by applying a liquid backing on a lower side of the carrier and allowing the liquid backing to solidify.

[0092] The incorporation of the artificial turf fiber into the carrier could, for example, be performed by tufting the artificial turf fiber into a carrier mesh and binding the tufted artificial turf fibers to the carrier mesh. For instance, the artificial turf fiber may be inserted with a needle into the carrier and tufted the way a carpet may be. If loops of the artificial turf fiber are formed, they may be cut during the same step. The method further comprises the step of binding the artificial turf fibers to the artificial turf carrier. In this step, the artificial turf fiber is bound or attached to the artificial turf carrier. This may be performed in a variety of ways, such as by gluing or coating the surface of

the artificial turf carrier to hold the artificial turf fiber in position. This, for instance, may be done by coating a surface or a portion of the artificial turf carrier with a material such as latex or polyurethane.

[0093] The incorporation of the artificial turf fiber into the carrier could, for example, be performed alternatively by weaving the artificial turf fiber into a carrier (or fiber mat) during manufacture of the artificial turf carpet. This technique of manufacturing artificial turf is known from United States patent application US 20120125474 A1.

[0094] A "thread-polymer" is understood here as any polymer that can be used to form threadlike regions within another polymer referred to herein as "base polymer" in the presence of a compatibilizer if the base polymer is extruded into a monofilament. Optionally, the monofilament can be stretched and the threadlike regions can be further elongated in the stretching process. The thread-polymer is preferably chosen to exhibit a high bending stiffness after being stretched into threadlike regions as described herein. The bending stiffness may be sufficiently high that no further means are needed to provide a desired level of resilience to an artificial turf fiber manufactured from the monofilament. In solid form, the thread-polymer may differ from the base polymer with regard to rigidity and/or density. The thread-polymer is immiscible with the base polymer. Preferably, the thread-polymer is a polar polymer. The thread-polymer is preferably an unaged polymer.

[0095] A "base polymer" may be any polymer that can be used to embed beads or threadlike regions of a polymer that is immiscible with the base polymer in the presence of a compatibilizer to form a monofilament as described herein for embodiments of the invention. The base polymer is preferably apolar, e.g., PE or PP. Preferably, an inexpensive polymer is chosen as the base polymer, as it is supposed to form the largest portion of the monofilament by mass and/or volume.

[0096] A "compatibilizer" as used herein is any substance that is capable of emulsifying a polymer that is immiscible with a base polymer in said base polymer. For example, a compatibilizer can be an amphiphilic substance that comprises a polar and an apolar portion and that can emulsify a polar polymer in the form of droplets or beads within an apolar base polymer phase, or can emulsify an apolar polymer in the form of droplets or beads within a polar base polymer phase. A "polymer" as used herein is preferably a polyolefin.

[0097] A "aged polymer" as used herein is a polymer or polymer mixture that was subject to an aging process. Preferably, an aged polymer is a polymer contained in and/or derived from "waste plastics". Typically, aged polymers are free of light stabilizers or comprise a significantly lower concentration of light stabilizers, e.g., HALS, than polymers contained in unaged plastic products. For example, an unaged artificial turf fiber polymer typically comprises at least 0.7% by weight HALS, e.g., 0.7 to 0.9 % HALS. After five years of exposing the fiber to sun, rain, and mechanical wear, the same fiber may comprise

less than 0.3 % HALS, and after some more years, the HALS content will typically fall below 0.1 %. In addition, aged polymers are often strongly oxidized and/or have a shorter main chain length and side chain length than the unaged polymers from which they derive. According to preferred embodiments, the aged polymer(s) used for creating the polymer mixture are not preprocessed for separating different types of aged polymers. Rather, the aged polymer(s) used for creating the polymer mixture can be a heterogeneous mix of shredded and optionally aggregated plastic waste from different sources and/or comprising different types of postconsumer plastic waste. According to embodiments, an aged polymer is a polymer exposed to sunlight and/or water for at least one year, e.g., polymers derived from outdoor products that have been in use for at least one year or polymers derived from plastic waste collected from the ocean, landfills, or other sources of waste.

[0098] An "IM polymer" as used herein is an aged polymer that is not miscible with the base polymer. The "not miscible" here means that the IM polymer and the base polymer form two separate phases when both polymers are heated above their respective melting temperature and do not intermix at least during the time interval between melting the IM polymer and the base polymer and extruding the liquid polymer mixture comprising the molten base polymer and the molten IM polymer. In some examples, the IM polymer and the base polymer are permanently immiscible, e.g. because the base polymer is apolar and the IM polymer is polar. In other examples, the IM polymer and the base polymer are only temporarily immiscible during the above mentioned time interval and would intermix if the time interval between melting both polymers and extruding the liquid polymer mixture would be significantly increased. In this example, the base polymer and the IM polymer may temporarily form separated phases due to differences in the melting temperature, differences in the viscosity and other factors. The time interval during which the two polymers are immiscible may depend on the respective polymer type used, and on the temperature. For many embodiments, the time interval between melting the IM polymer and the base polymer and performing the extrusion of the molten polymer mixture is shorter than 5 minutes, preferably shorter than 2 minutes, in particular shorter than 1 minute.

[0099] An "unaged polymer" (or "newly synthesized polymer", "newly produced polymer" or "virgin" polymer) as used herein is any polymer that has not been in use as a component of a product and has not been subject to an aging process. For example, an unaged polymer can be a polymer sold as a raw material to the polymer and plastic processing industry. In addition, or alternatively, the unaged polymer can be a polymer that was already processed by the polymer and plastic processing industry, e.g., by adding additional substances such as additives and pigments to the unaged polymer, but that was not yet in use as part of a product. Hence, the unaged polymer may in fact also be several years old, but - con-

trary to aged polymers - has not yet been exposed to sunlight, rain, or wear. According to embodiments, an unaged polymer is a polymer that was not exposed to sunlight for longer than a year. Preferably, an unaged polymer is a polymer that was not exposed to sunlight for longer than 6 month.

[0100] A "light stabilizer" as used herein is any substance that protects a plastic product from light-induced - in particular UV-induced - decay.

[0101] The term "polymer bead" (or "beads") may refer to a localized piece, such as a droplet, of a polymer that is immiscible in another polymer. The polymer beads may in some instances be round, spherical, or oval-shaped, but they may also be irregularly shaped. In some instances, the polymer beads will typically have a size of approximately 0.1 to 3 micrometers, preferably 1 to 2 micrometers in diameter. In other examples, the polymer beads will be larger. They may, for instance, have a diameter of a maximum of 50 micrometers.

Brief description of the drawings

[0102] In the following, embodiments of the invention are explained in greater detail, by way of example only, making reference to the drawings in which

Fig. 1 shows a diagram that illustrates a cross-section of a polymer mixture;

Fig. 2 shows a further example of a polymer mixture;

Fig. 3 shows a further example of a polymer mixture;

Fig. 4 shows a further example of a polymer mixture;

Fig. 5 shows a flowchart that illustrates an example of a method of manufacturing artificial turf;

Fig. 6 illustrates the extrusion of the polymer mixture into a monofilament;

Fig. 7 shows the integration of artificial turf fibers in a carrier;

Fig. 8A illustrates the effect of stretching the monofilament;

Fig. 8B shows an electron microscope picture of a cross-section of a stretched monofilament;

Fig. 9 shows three cross-sections of artificial turf fibers having a core-cladding structure; and

Fig. 10 shows an extrusion head for co-extruding two polymer masses.

Detailed Description

[0103] Like numbered elements in these figures are either equivalent elements or perform the same function. Elements that have been discussed previously will not necessarily be discussed in later figures if the function is equivalent.

[0104] Fig. 1 shows a diagram that illustrates a cross-section of a polymer mixture 100. The polymer mixture is at least a three-phase system, wherein the polymer mixture comprises a base polymer 102, preferably PE, at least one aged polymer referred to herein as "IM pol-

mer" 106 that it is immiscible with the base polymer, and a compatibilizer 104. Typically, but not necessarily, the plastic waste that is added to the polymer mixture and that comprises the IM polymer 106 will also comprise aged polymer types that are miscible with the base polymer and may (locally or globally throughout the whole mixture) form a blend with the base polymer (not shown). Typically, most of the plastic waste that is used for creating the polymer mixture consists of one or more aged polymers that are miscible with the base polymer.

[0105] The mixture 100 can be created, e.g., by adding the components of the mixture (base polymer, plastic waste comprising one or more IM polymers, the compatibilizer, and optional additives such as light stabilizers, flame retardants, or pigments) into an extruder and heating the components for performing the extrusion of the polymer mixture into a monofilament. The liquid polymer mixture can be, for example, formed immediately before and during the extrusion process by heating the components of the polymer mixture. The melting temperature used during extrusions is dependent upon the type of polymers and compatibilizer that is used. Typically, the melting temperature is between 230°C and 280°C.

[0106] The polymer mixture 100 can comprise two or more different types of aged polymers. The composition of the plastic waste used for creating the polymer mixture is typically not known. In fact, the plastic waste can be postconsumer waste whose polymer composition and/or degree of oxidation and decay vary greatly between different aged polymer batches supplied. For example, the aged polymers may be a mixture of two or more different polymers like PE, PA, PP, PET, and/or PBT. In some embodiments, the plastic waste that is used for creating the polymer mixture (and that comprises the IM polymer and optionally further IM polymers and polymers miscible with the base polymer) is derived from heterogeneous plastic waste. The heterogeneous plastic waste can comprise, e.g., old PET bottles, old artificial turf fibers, ocean plastic, plastic debris collected from biogas plants, or combinations thereof. Some of the different IM polymer types may be miscible with each other in a liquid state and form an IM polymer blend, and the plastic waste material used for creating the polymer mixture may optionally comprise further types of aged polymers that are not miscible with the IM polymers but may be miscible with the base polymer and hence do not correspond to a separate phase.

[0107] The base polymer 102 is an unaged polymer and typically provides at least 60% by weight of the polymer mixture 100. Often, more than 80 % or more than 90 % of the polymer mixture 100 consists of the base polymer. The base polymer and the IM polymer 106 (which can also be a blend of two or more different IM polymers) are immiscible. Therefore, the base polymer and the IM polymer 106 form two separate phases when the polymer mixture 100 is heated above the melting temperature of all polymers added to the mixture. The compatibilizer forms a third phase and prevents the separa-

tion of the base polymer and the IM polymer into two large separate volumes by surrounding and embedding beadlike volumes of the IM polymer within the base polymer phase. This embedding of a small volume of one phase within another phase is referred herein as "emulsification." The compatibilizer 104 emulsifies the IM polymer 102 within the base polymer phase.

[0108] According to one example, 20% of the depicted polymer mixture 100 consists of the IM polymer, e.g., old PA collected from an old, PA-based artificial turf field or other PA-based waste products. About 75 % of the polymer mixture consists of the base polymer, e.g., PE, which ensures that the artificial turf fiber to be created from the polymer mixture 100 has a smooth and elastic surface. Five percent of the polymer mixture consists of the compatibilizer.

[0109] According to another example, 7% of the depicted polymer mixture 100 consists of the IM polymer, e.g., old PET derived from plastic waste comprising PET polymers, e.g., some plastic bottles. About 88 % of the polymer mixture consists of the base polymer, e.g., PE, and about 5% of the polymer mixture consists of the compatibilizer.

[0110] The base polymer is not derived from plastic waste, but is rather an unaged polymer, i.e., it is either fabricated by the artificial turf fiber manufacturer or fabricated by a supplier of the fiber manufacturer and has not been used in any product before being used for creating the polymer mixture.

[0111] The compatibilizer can be, for example, maleic anhydride grafted on polyethylene or other types of compatibilizers mentioned herein.

[0112] The polymer mixture 100 is a multi-phase system (in particular, a system comprising at least three phases: a base polymer phase, a compatibilizer phase, and an IM polymer phase). The IM polymer can be a single type of aged polymer or can be a blend of two or more different types of IM polymers that are miscible with each other but not with the base polymer. The base polymer can be a single type of unaged polymer or can be a blend of two or more different types of base polymers that are miscible with each other but not with the IM polymer.

[0113] Fig. 2 shows a further example of a polymer mixture 200. The polymer mixture 200 is a four-phase system (base polymer 102, compatibilizer 104, IM polymer 106, thread-polymer 202). As explained already for the polymer mixture 100, the IM polymer can be a single type of aged polymer or can be a blend of two or more different types of IM polymers that are miscible with each other but not with the base polymer. The base polymer can be a single type of an unaged polymer or can be a blend of two or more different types of base polymers that are miscible with each other but not with the IM polymer. The thread-polymer 202 of the polymer mixture is a polymer that is immiscible with the base polymer and that is emulsified by the compatibilizer within the base polymer phase such that beadlike structures are formed

that are then transformed by the extrusion process and optional stretching steps into threadlike regions. The beadlike structures can basically consist of the unaged thread-polymer or can be a blend of the thread-polymer and one or more aged polymers (IM polymers) that are miscible with the thread-polymer but not with the base polymer. The thread-polymer is preferably a polymer that is more rigid in solid state than the base polymers. As a consequence, the thread-polymer improves the ability of artificial turf fibers to re-erect after and recover from being bent down by a ball or by the foot of a player.

[0114] In some examples, the thread-polymer is an unaged PA, and the base polymer is an unaged PE. PA in a solid state is more rigid than PE and is immiscible with the base polymer PE in a liquid state. The thread-polymer 202 may also be immiscible with the IM polymer 106 (e.g., PET), e.g., due to different melting temperatures. In this case, the unaged PA forms a further phase that is separate from the phase of the base polymer and of the phase of the IM polymer 106.

[0115] Additionally adding an unaged polymer that is immiscible with the base polymer and that preferably is more rigid than the base polymer may be advantageous as it may not be known whether a particular batch of plastic waste comprises a sufficient amount of a polymer that is immiscible with the base polymer and is adapted to increase the rigidity of the fiber by forming threadlike regions. Hence, the thread-polymer, e.g., an unaged PA, may ensure that at least a minimum number of threadlike regions are generated irrespective of the composition of the currently processed plastic waste batch.

[0116] According to one example, about 70 % of the polymer mixture 200 consists of the base polymer, e.g., PE; 5% of the polymer mixture consists of the compatibilizer. At least 4% of the polymer mixture 200, e.g., about 5 % of the polymer mixture 200, consists of a thread-polymer 202 (e.g., unaged PA). About 21 % of the depicted polymer mixture 200 consists of aged polymers (not shown). About a third of these aged polymers, i.e., about 7 % of the polymer mixture, form IM polymer 106 beads, which are emulsified by the compatibilizer 104 and which are neither miscible with the base polymer nor with the thread-polymer. The rest of these aged polymers, i.e., about 14 % of the polymer mixture, are aged polymers that are miscible with the base polymer (not shown). Adding at least 4 % of the unaged PA to the polymer mixture may ensure that even in cases where the plastic waste does not comprise a "rigid" polymer type that is immiscible with the base polymer and that is emulsified by the compatibilizer, the extrusion process will generate threadlike regions within the fiber for increasing the resilience of the fiber.

[0117] Fig. 3 shows a further example of a polymer mixture 300. The polymer mixture 300 comprises the following phases: a base polymer 102, a compatibilizer 104, and a plurality of different aged polymers 304, 106, 302. The aged polymers comprise a aged polymer 304 that is miscible with the base polymer and an IM polymer 106

of a first type and an IM polymer 302 of a second type. The mixture 300 can in some cases also comprise a thread-polymer 202. The first 106 and second 302 IM polymers are neither miscible with each other nor with the base polymer. The first IM polymer 106 can be a single IM polymer or a blend of two or more IM polymers that are miscible with each other but not with the base polymer. The second IM polymer 302 can be a single IM polymer or a blend of two or more IM polymers that are miscible with each other but not with the base polymer. Polymers derived from plastic waste often have different melting points even if they have the same polymer type. For example, depending on the chain length and on the branching pattern, different PA-based IM polymers may not be miscible at least temporarily during the heating and extrusion process, e.g., because a first PA-based IM polymer has a lower melting temperature than a second PA-based IM polymer. Hence, the first PA-based IM polymer may start forming liquid beads that are surrounded by the compatibilizer while the second PA-based IM polymer may still be contained in the mixture in a solid, granular form. The aged polymer 304 that is miscible with the base polymer 102 does not require a compatibilizer for intermixing with the base polymer. The aged polymer 304 may have a similar polarity or apolarity and a similar melt temperature as the base polymer, and hence may at least locally form polymer patches consisting of a blend of the aged polymer 304 with the base polymer. Aged polymers that are miscible with the base polymer will not delaminate from the base polymer in the extrusion product. For example, the aged polymer 304 could be old PE, e.g., PE derived from worn artificial turf.

[0118] Fig. 3 illustrates the advantages of using a compatibilizer: irrespective of whether the plastic waste used for creating the polymer mixture comprises a aged polymer that is miscible with the base polymer and/or a aged polymer that is not miscible with the base polymer, the compatibilizer will ensure that the extrusion product does not comprise a contact zone between two types of polymers that cannot intermix. Such contact zones reduce the quality of the product, as they may allow water to enter the fiber and may facilitate delamination of the fiber or fiber parts.

[0119] By adding a thread-polymer that preferably consists of or comprises an unaged polymer that is immiscible with the base polymer and that is more rigid than the base polymer, a minimum degree of resilience of the resulting fiber is achieved, whereby the resilience may be further increased by additional threadlike regions generated by the extrusion and - optionally - also the stretching of monofilaments comprising beads of the IM polymer.

[0120] In the depicted example, the same compatibilizer is used for the thread-polymer, the first IM polymer, and the second IM polymer. In other embodiments, different compatibilizers could be used for each of the different polymer types 106, 202, 302, and a compatibilizer mixture can be added to the polymer mixture to ensure

that any or at least many types of aged polymers that may be contained in the plastic waste used for manufacturing the artificial turf fiber will either form a blend with the base polymer or are emulsified by one of the multiple compatibilizers within the base polymer phase.

[0121] Fig. 4 shows a further example of a polymer mixture 400. The polymer mixture 400 comprises the following phases: a base polymer 102, a compatibilizer 104, and a thread-polymer, whereby the thread-polymer forms beads that are surrounded by the compatibilizer and that comprise a blend 402 of an IM polymer 106 and the unaged thread-polymer. The thread-polymer is miscible with the IM polymer but is not miscible with the base polymer. For example, the IM polymer can be an old PA and the thread-polymer can be an unaged PA. It is not necessary - and typically also not feasible - to determine the exact composition and/or the exact PA content of plastic waste. Nevertheless, in many cases, heterogeneous plastic waste derived, e.g., from old artificial turf, may comprise a significant portion of a polymer that is miscible with an unaged PA. This may allow reducing the amount of unaged PA that has to be added to a polymer mixture in order to provide thread-polymer beads in sufficient number and size.

[0122] Fig. 5 shows a flowchart that illustrates an example of a method of manufacturing artificial turf fibers 710 as depicted, for example, in figure 7.

[0123] First, in step 502, a liquid polymer mixture 100, 200, 300, 400 is created. The polymer mixture is at least a three-phase system. The polymer mixture comprises a base polymer made of an unaged polymer, one or more aged polymers made of plastic waste material, and a compatibilizer. The aged polymers comprise at least one aged polymer (referred herein as "IM polymer") that is not miscible with the base polymer. Various examples for the polymer mixture are depicted and described, for example, in figures 1-4.

[0124] The base polymer and the IM polymer are immiscible. In other examples the polymer mixture may comprise additional polymers, such as an unaged polymer used as a thread-polymer and/or one or more additional IM polymers, that are immiscible with the base polymer and with each other. The IM polymers may be immiscible with each other, e.g., because of different melt temperatures. In some embodiments, the liquid polymer mixture is heated in only 10 to 30 seconds from room temperature to the extrusion temperature. Hence, the time during which different polymer droplets may merge is quite short. Small differences in the melt temperature may have a huge impact on the miscibility of different aged polymers. Therefore, it is possible that in the liquid polymer mixture generated in the extruder, two or more aged polymers cannot mix with each other and cannot mix with the base polymer, although they would be able to generate a blend with the other aged polymers and/or the blend if they were stirred for several minutes and heated above the melt temperatures of all said polymers.

[0125] Typically, the base polymer is an apolar polymer

like PE. The majority of polymer types contained in heterogeneous plastic waste is also often apolar. Hence, the largest portion of the plastic waste that provides the one or more aged polymers may consist of apolar polymers. Often, only a small part of about 0.1 to 20% of the waste plastic is made of apolar polymers that act as IM polymers if mixed with an apolar base polymer. These miscible aged polymers typically form a blend with the base polymer and do not increase the tendency of the monofilament to delaminate. Embodiments also ensure that traces of aged polymers that are immiscible with the base polymer, e.g., because of their polarity, will not cause the monofilament to delaminate.

[0126] In some embodiments, the liquid polymer mixture may comprise multiple different compatibilizers that are used for emulsifying different types of IM polymers, thereby ensuring that any type of polymer that is immiscible with the base polymer forms polymer beads surrounded by the compatibilizer. The polymer beads may also be formed by additional polymers that are not miscible in the base polymer.

[0127] Next, in step 504, the polymer mixture is extruded into a monofilament 606, 900, 950.

[0128] Next, in step 506, the artificial turf fiber is fabricated from one or more of the monofilaments.

[0129] In some embodiments, the artificial turf fiber is created as follows: A polymer mixture 100, 200, 300, 400 is created in step 502 by combining a base polymer, a compatibilizer, and plastic waste in a heatable container, e.g., an extruder. The plastic waste will comprise at least one IM polymer that is emulsified by the compatibilizer and forms beads within the base polymer phase when the components of the mixture are heated above the melt temperature of the components.

[0130] If a thread-polymer is added as a further component, the liquid polymer mixture will also comprise beads consisting of the thread-polymer or a thread-polymer/IM polymer blend. The polymer beads comprising an IM polymer and/or comprising a thread-polymer or a blend of a thread-polymer and an IM polymer are, respectively, surrounded by the compatibilizer when the components of the polymer mixture are heated in an extruder for being extruded in step 504 through one or more extrusion holes into a monofilament.

[0131] Next, in step 506, the monofilament is quenched or rapidly cooled down. After the monofilament has been cooled down, it is reheated in step 508 and the reheated monofilament is stretched in step 510 to deform the polymer beads into threadlike regions and to form the monofilament into the artificial turf fiber. Additional steps may also be performed on the monofilament to form the artificial turf fiber. For instance, the monofilament may be spun or woven into an artificial turf fiber with desired properties.

[0132] The artificial turf fiber is incorporated in step 512 into an artificial turf backing.

[0133] Step 512 could, for example, be, but is not limited to, tufting or weaving the artificial turf fiber into a

carrier mesh in step 514.

[0134] Then, in step 516, the artificial turf fibers are bound to the artificial turf backing. For instance, the artificial turf fibers may be glued or held in place by a coating or other material that may be applied in fluid state onto the lower side of the carrier mesh. Step 518 comprises allowing the fluid to solidify into a film that mechanically fixes the fibers in the carrier.

[0135] Steps 516 and 518 are optional steps. For example, if the artificial turf fibers are woven into the carrier, steps 516 and 518 may not need to be performed.

[0136] According to one example, plastic waste is shredded into aged polymer granules. The aged polymer granules are mixed with a compatibilizer. Color pigments, UV and thermal stabilizers, process aids, and other substances that are as such known from the art can be added to the mixture. This may result in a system in which the aged polymer granules comprising one or more IM polymers and optionally one or more aged polymers that are miscible with the base polymer are surrounded by the compatibilizer. The exact composition of the aged polymers may be unknown.

[0137] In a second step, the base polymer is added to the mixture whereby in one example the quantity of the base polymer is about 50 to 80 % by weight of the polymer mixture to be generated. In some embodiments, the one or more aged polymers (that are miscible or immiscible with the base polymer) are e.g. 15% to 40 % by weight of the polymer mixture and of the compatibilizer is about 5% to 10% by weight of the polymer mixture. Using extrusion technology results in a mixture of droplets or of beads of the IM polymer surrounded by the compatibilizer that is dispersed in the polymer matrix of the base polymer. In a practical implementation, a so-called master batch including granulate of the aged polymers and the compatibilizer is formed. The master batch may also be referred to as a "polymer mixture" herein. The granulate mix is melted and a mixture of aged polymer(s) and the compatibilizer that surrounds IM polymers contained in the aged polymers is formed by extrusion. The resulting strands are crushed into granulate. The resultant granulate and granulate of the base polymer are then used in a second extrusion to produce the thick fiber which is then stretched into the final fiber.

[0138] The melt temperature used during extrusions is dependent on the type of polymers and compatibilizer that are used. However, the melt temperature is typically between 230°C and 280°C.

[0139] A monofilament, which can also be referred to as a filament or fibrillated tape, is produced by feeding the mixture into a fiber-producing extrusion line. The melt mixture passes the extrusion tool, i.e., a spinneret plate or a wide slot nozzle, forming the melt flow into a filament or tape form, is quenched or cooled in a water spin bath, and is dried and stretched by passing rotating heated godets with different rotational speeds and/or a heating oven.

[0140] The monofilament or type is then annealed on-

line in a further step passing a further heating oven and/or set of heated godets.

[0141] Through this procedure, the beads or droplets of the IM polymer(s), surrounded by the compatibilizer, are stretched into a longitudinal direction and form small, fiberlike, linear structures that stay completely embedded in the polymer matrix of the base polymer.

[0142] Fig. 6 illustrates the extrusion of the polymer mixture 100 into a monofilament 606. Within the polymer mixture 600 there are a large number of polymer beads. The polymer beads may be made of one or more polymers that are not miscible with the base polymer and are separated from the base polymer by a compatibilizer. A screw, piston, or other device is used to force the polymer mixture 100 through a hole 602 in a plate 604. This causes the polymer mixture 100 to be extruded into a monofilament 606. The monofilament 606 is shown as containing a polymer bead 608 that is elongated during the extrusion process to form a threadlike region. In some examples, the base polymer will be less viscous than the IM polymer(s) and/or thread-polymers in the beads, and the polymer beads will tend to concentrate in the center of the monofilament 606. This may lead to desirable properties for the final artificial turf fiber, and this may lead to a concentration of the threadlike regions in the core region of the monofilament 606.

[0143] Examples may relate to the production of artificial turf, which is also referred to as synthetic turf. In particular, the invention relates to the production of fibers that imitate grass. The fibers are composed of first and second polymers that are not miscible and differ in material characteristics, such as the stiffness, density, polarity, and compatibilizer.

[0144] Fig. 7 shows an example of a cross-section of an example of artificial turf 700 and shows the integration of artificial turf fibers 710 in a carrier 706. The artificial turf 700 comprises an artificial turf backing 708 that may, e.g., be latex-based or PU-based. Artificial turf fiber 710 has been tufted into the carrier 706, e.g., a textile carrier mesh. The backing 708 is on the lower side of the carrier and embeds U-shaped portions of the integrated fibers, thereby serving to bind or secure the artificial turf fiber 710 to the artificial turf carrier. The backing 708 may be optional. For example, the artificial turf fibers 710 may be alternatively woven into the carrier mesh. Various types of glues, coatings, or adhesives could be used for the backing 708. The artificial turf fibers 710 are shown as extending a distance 704 above the artificial turf carrier 706. The distance is essentially the height of the pile of the artificial turf fibers. The length of the threadlike regions within the artificial turf fibers is half of the distance 704 or less.

[0145] Fig. 8A shows a cross-section of a small segment 800 of the monofilament 606 and illustrates the effect of extruding and stretching the monofilament on the beads contained therein. The monofilament is again shown as comprising the base polymer with the polymer beads comprising the IM polymer and/or the thread-pol-

ymers mixed in. The polymer beads are separated from the base polymer by a compatibilizer, which is not shown. In Fig. 8A, an example of a cross-section of a monofilament 606 that has been extruded and stretched is shown. To form the threadlike structures, a section of the monofilament 606 is heated and then stretched along the length of the monofilament 606. The polymer beads in Figs. 1 to 4 have been stretched into threadlike structures 802. The amount of deformation of the polymer beads would be dependent on the extrusion speed and upon how much the monofilament 606 has been stretched.

[0146] Fig. 8B shows an electron microscope picture of a cross-section of a stretched monofilament. Figure 8B more faithfully reproduces the dimensions of the threadlike regions relative to the diameter of the monofilament than does the schematic drawing of Fig. 8A. The horizontal white streaks within the stretched monofilament 606 are the threadlike regions 802. The threadlike structures 802 can be shown as forming small linear structures of the IM polymer and/or the thread-polymer (or an IM-polymer-thread-polymer-blend) within the base polymer phase.

[0147] The resultant fiber may have multiple advantages, namely softness combined with durability and long-term elasticity. In cases of different stiffness and bending properties of the polymers, the fiber can show a better resilience (this means that once a fiber is stepped on it will spring back). In cases of a stiff IM polymer and/or thread-polymer, the small linear fiber structures built into the polymer matrix are providing a polymer reinforcement of the fiber.

[0148] Delimitation due to the composite formed by the IM polymer and base polymer is prevented due to the fact that the short fibers of the IM polymer are embedded in the matrix given by the base polymer. Moreover, complicated co-extrusion, requiring several extrusion heads to feed one complex spinneret tool, is not needed.

[0149] The IM polymer can be a polar substance, such as polyamide, whereas the base polymer can be an apolar polymer, such as polyethylene. Alternatives for the IM polymer are PET or PBT, and for the base polymer, polypropylene. Finally, a material consisting of three polymers is possible (e.g., PET, PA, and PP), with PP creating the matrix and the others creating independently from other fibrous linear structures. The compatibilizer can be a maleic anhydride grafted on polyethylene or polyamide.

[0150] Fig. 9 shows three cross-sections of artificial turf fibers having a core-cladding structure.

[0151] Fig. 9A shows a cross-section of an artificial turf fiber 900 created by concentric co-extrusion of at least a first polymer mass 902 and a second polymer mass 904. The fiber 900 is created by extruding the first and the second polymer mass together through a common extrusion path such that the first polymer mass is concentrically surrounded by the second polymer mass 904 and such that the two polymer masses are in contact (at a contact area 906 depicted in figures 9B and C) while being co-extruded through the common extrusion path. The

first polymer mass 902 is the polymer mixture 100, 200, 300, 400 created in a method according to any one of the embodiments and examples described herein. The first polymer mass may also be referred to as a "core polymer mass." The second polymer mass 904 is an unaged cladding polymer. The cladding polymer is miscible with the base polymer of the core polymer mass.

[0152] This may be advantageous, as the cladding polymer 902 is identical to and miscible with the base polymer of the core 902, thereby preventing any delamination of the cladding and the core at the contact zone 906. Moreover, according to preferred embodiments, pigments, flame retardants, and/or light stabilizers are selectively added to the second polymer mass 904, forming the cladding polymer. This may allow lowering the production costs without reducing the quality of the fiber.

[0153] In a further beneficial aspect, using the concentric core-cladding structure as depicted in figures 9A to C may ensure that even in cases where the mechanical properties of the polymer mixture 100, 200, 300, 400 should be worsened by a large portion of an aged polymer that intermixes with the base polymer, the fibers 900, 950 do not have these worsened mechanical properties because they have a shell/cladding that is completely made of an unaged polymer, e.g., PE or PP.

[0154] Figs. 9B and 9C show another embodiment of a fiber 950, having a core-cladding structure, whereby the core is made of a mixture described herein for embodiments of the invention and whereby the cladding is made of an unaged polymer that is identical to the base polymer of the core 902. The fiber 950 comprises two protrusions 904 that consist of the cladding polymer and that increase the surface-to-mass ratio of the fiber.

[0155] According to one example, the monofilaments 900, 950 formed by co-extrusion of the core polymer mass 902 with the cladding polymer mass 904 may already feature a robust bond between core and cladding. A high elasticity offered by a rigid thread-polymer may be reached by elongating and stretching the beads into threadlike regions whose elasticity follows the same principle as that of a leaf spring. This extension may be achieved by reheating the monofilament and stretching it over a controlled length ratio. As a result, an artificial turf fiber is formed, which may feature a high resilience due to a highly elastic core, optimized surface properties due to an appropriate choice of the cladding polymer, and inherent protection from splicing or delamination due to a highly stable contact layer where the core polymer is mixed with the cladding polymer.

[0156] Embodiments of the invention include forming the artificial turf fiber 950 with particular geometry features of the noncircular profile.

[0157] Fig. 10 shows an extrusion head with two separate openings for two different polymer masses that allows generating an artificial turf fiber monofilament 900, 950 having a core-shell structure in a co-extrusion process.

[0158] The first polymer mass 902, also referred to as

a core polymer mass, is fed through a first opening into a duct that is located at the center of the extrusion head. The second polymer mass 904, also referred to as a cladding polymer mass, is fed through one or more further openings into a second duct that concentrically surrounds the first duct.

[0159] At first, the liquid cladding polymer 904 and the liquid core polymer 902 are transported along their respective ducts toward the opening 602 of the extrusion head. The transportation of the polymer masses in their respective ducts is performed such that the two polymer masses are transported in a basically laminar flow. While the two polymer masses are transported in their respective ducts, an intermixing of the core and the cladding polymer mass is prohibited by the walls of the inner duct. The first duct used for transporting the core polymer mass is shorter than the second duct used for transporting the cladding polymer mass. As a result, the two polymer masses get in contact with each other when the core polymer mass leaves the end of the inner duct. The portion where the core and the cladding polymer mass get in contact with each other and can intermix at the contact area 906 is referred herein as a "joining path" 960.

[0160] According to embodiments, the extrusion opening is located downstream of the joining path 960 wherein the core and cladding polymer masses 902, 904 are allowed to contact each other while moving in a parallel, with a laminar flow toward the opening 602. This may allow the core and cladding polymer to intermix at the contact zone 906, thereby preventing a delamination of the cladding from the core.

[0161] The length, diameter, and feeding rate of both polymers is chosen such that the core polymer mass and the cladding polymer mass contact each other such that a contact layer 906 is formed between the core polymer mass and the cladding polymer mass, the contact layer comprising a mixture of the core polymer mixture and the cladding polymer mass. This may be achieved by controlling the flow characteristics (streaming pattern, velocity distribution, viscosities, shear moduli, temperature, melt flow indices, etc.) during the joining such that a stable, small-scale turbulence is created, which causes the two polymer masses to intermix in a thin region 906 interfacing the core polymer mixture and the cladding polymer component. This may strengthen the cohesion between the core and cladding of the finished artificial turf fiber.

[0162] According to embodiments, the core polymer mass and the cladding polymer mass are pressed concentrically along the joining path 960, the core polymer, and the cladding polymer, being allowed to mix along the joining path to form the contact layer 906. The contact layer is formed within an axial length of the joining path of three to seven times the diameter of the inner duct used for transporting the core polymer mass at the upstream end of the joining path 960. According to embodiments, the diameter of the core polymer mixture at the upstream end of the joining path is between 0.5 and 1.5

mm, preferably 1.25 mm. This may allow for adjusting the length of the joining path to the specific properties, such as viscosity, melt flow index, or shear modulus, of the polymer components to be brought into contact and to the specific process parameters, like temperature or pressure, to provide beneficial rheological properties for establishing a firm bond between the core and the cladding of the fiber. The flow in the joining path should be maintained at a stable, small-scale turbulence. If the length of the joining path is too long, turbulence may get suppressed by feedback of increased wall-polymer interaction. On the other hand, a too-short joining path may destroy the stability of the turbulence such that the contact layer becomes variable, e.g., in thickness and position. A fiber produced with a too-short joining region may show no beneficial surface properties anymore which are supposed to arise from a clear distinction between the core and cladding.

[0163] According to embodiments, the core of the fiber has a diameter of 50 to 600 micrometers, and the cladding is formed with a minimum thickness of 25 to 300 micrometers in all directions extending radially from the core. Each of the protrusions, if any, is formed with a radial extension in a range of two to 10 times the radius of the core. As explained further above, the mentioned ranges for the core diameter and the minimum cladding thickness may be beneficial for providing the desired degree of stiffness and a sufficient amount of cladding material surrounding the core to form the mechanically robust contact layer. Said ratio of the radial extension of the protrusions with respect to the core radius may be chosen so as to improve the biomimetic properties of the artificial turf and the surface-to-mass ratio of the artificial turf fibers.

[0164] According to embodiments, the core polymer mass is free from at least one of the following components of the cladding: a wax, a dulling agent, a UV stabilizer, a flame retardant, an antioxidant, a fungicide, a pigment, and combinations thereof. It may be beneficial to use one or more of the mentioned additives only in the cladding where they are actually needed. This may allow for a more cost-effective production method, as fewer additives are consumed per unit length of the artificial turf fiber.

[0165] According to embodiments, the core polymer is high-density polyethylene (HDPE) and the cladding polymer is a linear low-density polyethylene (LLDPE). In liquefied form, this combination may feature a high miscibility with each other as well as rheological properties that are optimized for forming a firm bond between core and cladding by means of co-extrusion. When formed into a monofilament for producing an artificial turf fiber according to the embodiments of the invention, the two solidified polymers may provide further advantages: HDPE is denser and more rigid than LLDPE, which may, thus, add to the resilience of the artificial turf fiber, while LLDPE is soft and wear-resistant, which may provide a reduced risk of injury and enhanced durability.

[0166] The opening 602 of the extrusion head can have a circular profile, resulting in a monofilament profile as depicted in Fig. 9A.

[0167] Alternatively, the opening 602 can have a non-circular profile. According to embodiments, the resulting monofilament profile comprises one or more protrusions that extend from the core in opposite directions, as depicted in figures 9B and 9C.

List of reference numerals

[0168]

100	polymer mixture
102	Base polymer
104	compatibilizer
106	aged polymer (IM polymer)
200	polymer mixture
202	thread-polymer
300	polymer mixture
302	aged polymer (IM polymer)
304	aged polymer, miscible with base polymer
400	polymer mixture
402	blend of thread-polymer and IM polymer
502-518	steps
602	extrusion opening
604	extruder plate
606	extruded monofilament
608	elongated beadlike structure
700	artificial turf
702	cutting tufted fibers
704	fiber portions protruding from the carrier
706	carrier
708	backing
710	artificial turf fibers
800	section of a monofilament
802	threadlike regions
900	monofilament
902	first polymer mass (core polymer)
904	second polymer mass (cladding polymer)
906	contact area core/cladding polymer
950	monofilament
970	extrusion head of co-extruder
960	joining path

Claims

1. A method of manufacturing an artificial turf fiber (710), the method comprising:
 - providing plastic waste comprising one or more aged polymers (106, 302, 304),
 - providing a base polymer (102), 302, 304), the base polymer being an unaged polymer,
 - heating and mixing the plastic waste and the base polymer and a compatibilizer (104) for creating (502) a liquid polymer mixture (100, 200,

300, 400), wherein the one or more aged polymers comprise an IM polymer (106, 302) that is not miscible with the base polymer, wherein the liquid polymer mixture is a multi-phase system and wherein the compatibilizer emulsifies the IM polymer within the base polymer phase such that the IM polymer forms polymer beads surrounded by the compatibilizer within the base polymer phase;

- extruding (504) the liquid polymer mixture into a monofilament (606); and

- fabricating the artificial turf fiber from one or more of the monofilaments.

2. The method of claim 1, wherein the base polymer is polyethylene.

3. The method of any one of the previous claims, wherein the IM polymer is polypropylene, polyamide, polyethylene-terephthalate, and/or polyethylene.

4. The method of any one of the previous claims, wherein the IM polymer is polar and/or wherein the base polymer is apolar.

5. The method of any one of the preceding claims, wherein 1 to 40 % by weight of the polymer mixture consists of the plastic waste; in particular, at least 10 percent by weight of the polymer mixture consists of the plastic waste.

6. The method of any one of the previous claims, wherein the polymer mixture comprises a thread-polymer (202, 106, 302, 402), the thread-polymer being an unaged polymer that is immiscible with the base polymer phase, wherein the compatibilizer emulsifies the thread-polymer (202) or a blend (402) of the thread-polymer and the IM polymer within the base polymer phase such that the thread-polymer (202) or the blend (402) forms polymer beads surrounded by the compatibilizer within the base polymer phase.

7. The method of any one of the previous claims, further comprising:

- quenching (104) the extruded monofilament;
- reheating (106) the quenched monofilament;
- stretching (108) the reheated monofilament to deform the polymer beads into threadlike regions (802), wherein the artificial turf fiber is fabricated from one or more stretched monofilaments.

8. The method of any one of the previous claims 5 to 7, wherein the thread-polymer is a polar polymer, in particular polyamide or polyethylene-terephthalate, or a mixture of unaged polar polymers having basically identical melting temperatures.

9. The method of any one of the previous claims, wherein the base polymer phase consists of the liquid base polymer or a blend of the liquid base polymer and one or more of the aged polymers which are miscible with the unaged base polymer. 5
10. The method of any one of the previous claims, wherein the compatibilizer is any one of the following: a maleic acid grafted on polyethylene or polyamide; a maleic anhydride grafted on free radical initiated graft copolymer of polyethylene, SEBS, EVA, EPD, or polypropylene, with an unsaturated acid or its anhydride such as maleic acid, glycidyl methacrylate, ricinoleoxazoline maleinate; a graft copolymer of SEBS with glycidyl methacrylate, a graft copolymer of EVA with mercaptoacetic acid and maleic anhydride; a graft copolymer of EPDM with maleic anhydride; a graft copolymer of polypropylene with maleic anhydride; a polyolefin-graft-polyamidopolyethylene or polyamide; and a polyacrylic acid type compatibilizer. 10 15 20
11. The method of any one of the previous claims, wherein the polymer mixture comprises 60 to 99 percent by weight the base polymer. 25
12. The method of any one of the previous claims, wherein the plastic waste is a shredded, cut, crushed, minced or grinded plastic waste of heterogeneous origin, in particular shredded postconsumer plastic waste. 30
13. The method of any one of the previous claims, wherein the plastic waste consists of or comprises ocean plastics. 35
14. The method of any one of the previous claims, wherein the plastic waste comprises used artificial turf fibers, in particular a mixture of different types of used artificial turf fibers. 40
15. The method of any one of the previous claims, wherein the extrusion is a co-extrusion of at least a first polymer mass (902) and a second polymer mass (904), the co-extrusion comprising: 45
- extruding the first and the second polymer mass together through a common extrusion path such that the first polymer mass is concentrically surrounded by the second polymer mass and such that the two polymer masses are in contact (906) while being co-extruded through the common extrusion path; wherein the first polymer mass (902) is the polymer mixture (100, 200, 300, 400) created in a method according to any one of the previous claims; and wherein the second polymer mass (904) is an unaged cladding polymer, the cladding polymer being 50
- miscible with the base polymer.
16. The method of any one of the previous claims, wherein: 5
- the IM polymer is a polymer comprising less than 0.3 % by weight a light stabilizer; and/or
 - the IM polymer is a polymer having a melt flow index of 5.0 to 7.0 g/10 min. 10
17. A method of manufacturing artificial turf (700), the method comprising: 15
- incorporating (512) a plurality of artificial turf fibers (710) manufactured according to any one of the previous claims into a carrier (706). 20
18. An artificial turf fiber (710) manufactured according to the method of any one of the preceding claims.
19. An artificial turf fiber (710) comprising at least one monofilament (606), wherein each of the at least one monofilament comprises: 25
- a base polymer mass (102) comprising or consisting of a base polymer, the base polymer being an unaged polymer;
 - threadlike regions comprising one or more aged IM polymers (106, 302), the one or more aged IM polymers being aged polymers (106, 302) that are not miscible with the base polymer in liquid state;
 - a compatibilizer (104), wherein the compatibilizer embeds and surrounds the threadlike regions and embeds the threadlike regions within the base polymer mass. 30 35
20. An artificial turf (700) comprising a textile carrier (706) and an artificial turf fiber (710) according to claim 19, the fiber being incorporated into the carrier. 40
- Amended claims in accordance with Rule 137(2) EPC.**
1. A method of manufacturing an artificial turf fiber (710), the method comprising: 45
- providing plastic waste comprising one or more aged polymers (106, 302, 304),
 - providing a base polymer (102), the base polymer being an unaged polymer,
 - heating and mixing the plastic waste and the base polymer and a compatibilizer (104) for creating (502) a liquid polymer mixture (100, 200, 300, 400), wherein the one or more aged polymers comprise an IM polymer (106, 302) that is not miscible with the base polymer, wherein the 50 55

- liquid polymer mixture is a multi-phase system and wherein the compatibilizer emulsifies the IM polymer within the base polymer phase such that the IM polymer forms polymer beads surrounded by the compatibilizer within the base polymer phase;
- extruding (504) the liquid polymer mixture into a monofilament (606); and
 - fabricating the artificial turf fiber from one or more of the monofilaments.
2. The method of claim 1, wherein the base polymer is polyethylene.
 3. The method of any one of the previous claims, wherein the IM polymer is polyamide, and/or polyethylene-terephthalate.
 4. The method of any one of the previous claims, wherein the IM polymer is polar and/or wherein the base polymer is apolar.
 5. The method of any one of the preceding claims, wherein 1 to 40 % by weight of the polymer mixture consists of the plastic waste; in particular, at least 10 percent by weight of the polymer mixture consists of the plastic waste.
 6. The method of any one of the previous claims, wherein the polymer mixture comprises a thread-polymer (202), the thread-polymer being an unaged polymer that is immiscible with the base polymer phase, wherein the compatibilizer emulsifies the thread-polymer (202) or a blend (402) of the thread-polymer and the IM polymer within the base polymer phase such that the thread-polymer (202) or the blend (402) forms polymer beads surrounded by the compatibilizer within the base polymer phase.
 7. The method of any one of the previous claims, further comprising:
 - quenching (104) the extruded monofilament;
 - reheating (106) the quenched monofilament;
 - stretching (108) the reheated monofilament to deform the polymer beads into threadlike regions (802), wherein the artificial turf fiber is fabricated from one or more stretched monofilaments.
 8. The method of any one of the previous claims 5 to 7, wherein the thread-polymer is a polar polymer, in particular polyamide or polyethylene-terephthalate, or a mixture of unaged polar polymers having identical melting temperatures.
 9. The method of any one of the previous claims, wherein the base polymer phase consists of the liquid base polymer or a blend of the liquid base polymer and one or more of the aged polymers which are miscible with the unaged base polymer.
 10. The method of any one of the previous claims, wherein the compatibilizer is any one of the following: a maleic acid grafted on polyethylene or polyamide; a maleic anhydride grafted on free radical initiated graft copolymer of polyethylene, SEBS, EVA, EPD, or polypropylene, with an unsaturated acid or its anhydride such as maleic acid, glycidyl methacrylate, ricinoloazoline maleinate; a graft copolymer of SEBS with glycidyl methacrylate, a graft copolymer of EVA with mercaptoacetic acid and maleic anhydride; a graft copolymer of EPDM with maleic anhydride; a graft copolymer of polypropylene with maleic anhydride; a polyolefin-graft-polyamidepolyethylene or polyamide; and a polyacrylic acid type compatibilizer.
 11. The method of any one of the previous claims, wherein the polymer mixture comprises 60 to 99 percent by weight the base polymer.
 12. The method of any one of the previous claims, wherein the plastic waste is a shredded, cut, crushed, minced or grinded plastic waste of heterogeneous origin, in particular shredded postconsumer plastic waste.
 13. The method of any one of the previous claims, wherein the plastic waste consists of or comprises plastics collected from the ocean.
 14. The method of any one of the previous claims, wherein the plastic waste comprises used artificial turf fibers, in particular a mixture of different types of used artificial turf fibers.
 15. The method of any one of the previous claims, wherein the extrusion is a co-extrusion of at least a first polymer mass (902) and a second polymer mass (904), the co-extrusion comprising:
 - extruding the first and the second polymer mass together through a common extrusion path such that the first polymer mass is concentrically surrounded by the second polymer mass and such that the two polymer masses are in contact (906) while being co-extruded through the common extrusion path; wherein the first polymer mass (902) is the polymer mixture (100, 200, 300, 400) created in a method according to any one of the previous claims; and wherein the second polymer mass (904) is an unaged cladding polymer, the cladding polymer being miscible with the base polymer.

16. The method of any one of the previous claims, wherein:

- the IM polymer comprises less than 0.3 % by weight a light stabilizer; and/or 5
- the IM polymer has a melt flow index of 5.0 to 7.0 g/10 min.

17. A method of manufacturing artificial turf (700), the method comprising: 10

- incorporating (512) a plurality of artificial turf fibers (710) manufactured according to any one of the previous claims into a carrier (706). 15

18. An artificial turf fiber (710) manufactured according to the method of any one of the preceding claims.

19. An artificial turf fiber (710) comprising at least one monofilament (606), wherein each of the at least one monofilament comprises: 20

- a base polymer mass (102) comprising or consisting of a base polymer, the base polymer being an unaged polymer; 25
- threadlike regions comprising one or more aged IM polymers (106, 302), the one or more aged IM polymers being aged polymers (106, 302) that are not miscible with the base polymer in liquid state; 30
- a compatibilizer (104), wherein the compatibilizer embeds and surrounds the threadlike regions and embeds the threadlike regions within the base polymer mass. 35

20. An artificial turf (700) comprising a textile carrier (706) and an artificial turf fiber (710) according to claim 19, the fiber being incorporated into the carrier. 40

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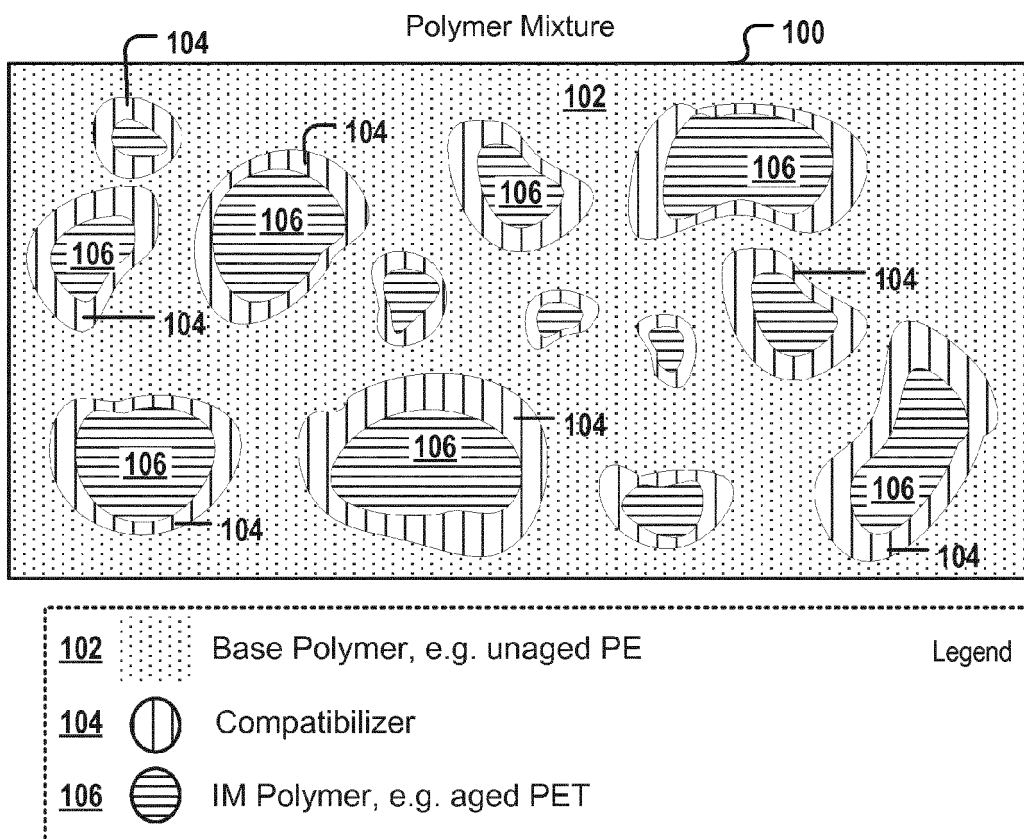


Fig. 1

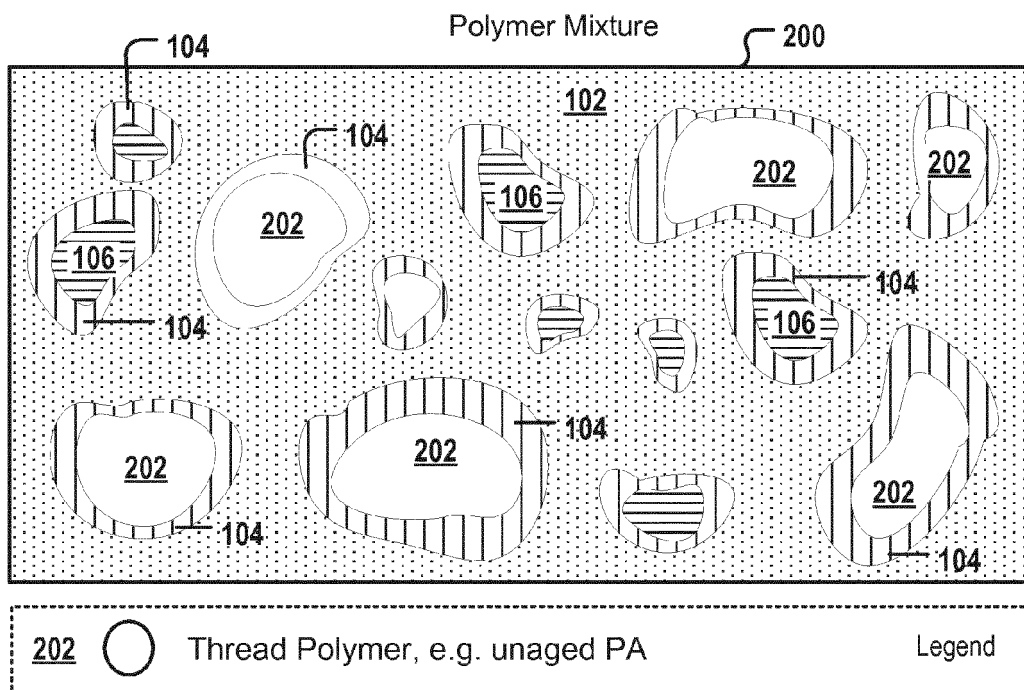
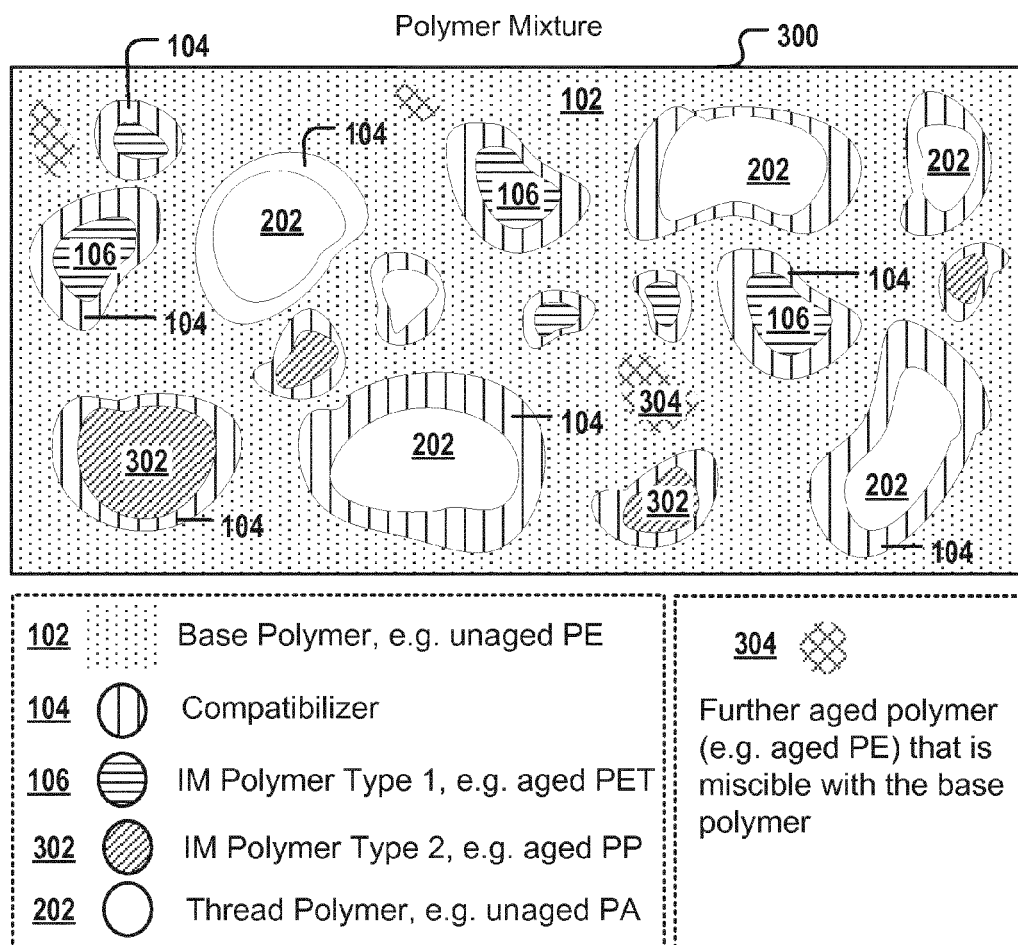
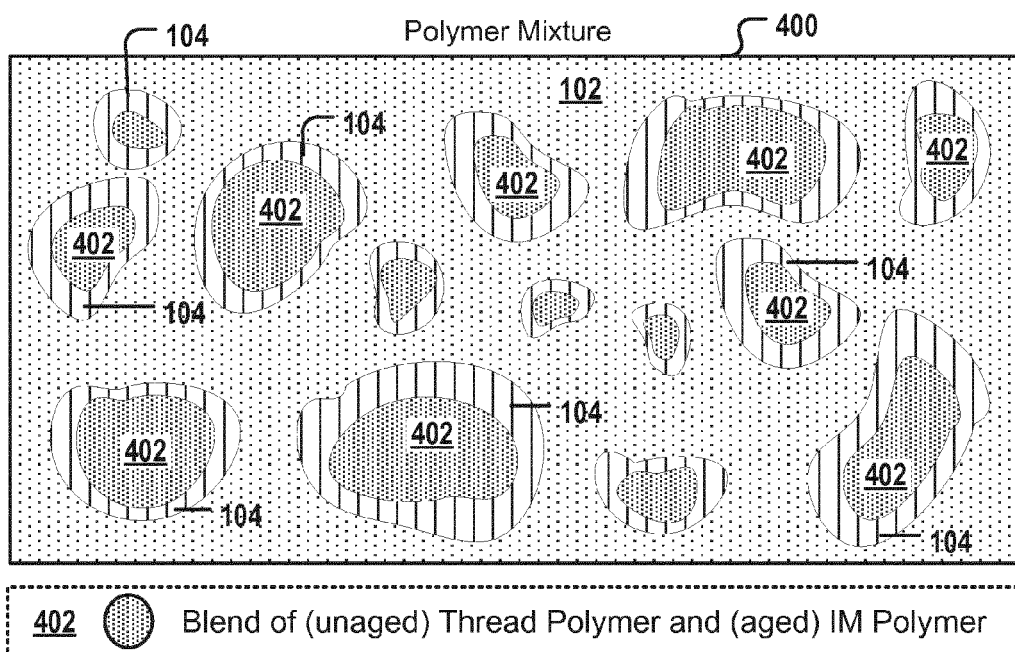
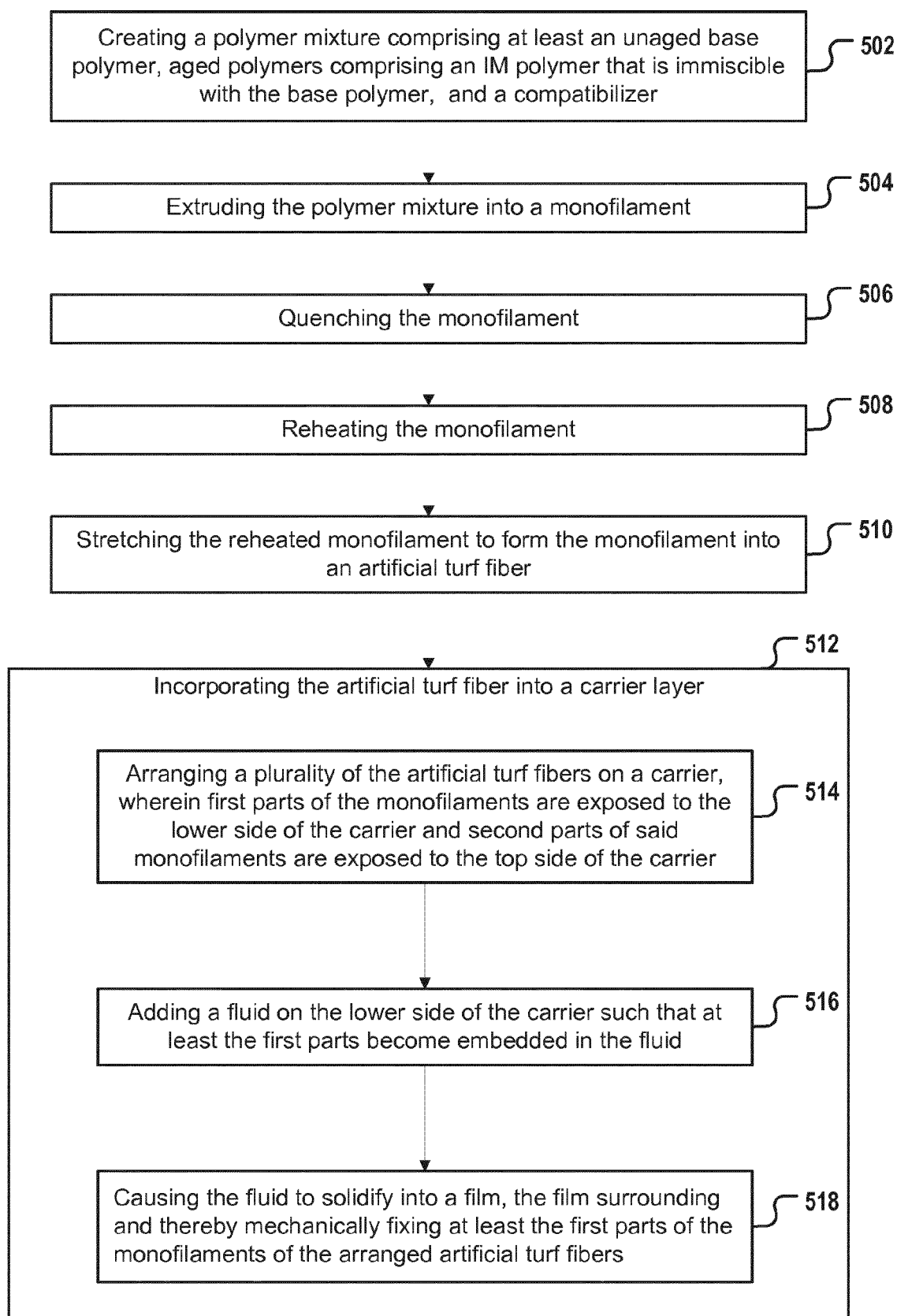


Fig. 2

**Fig. 3****Fig. 4**

**Fig. 5**

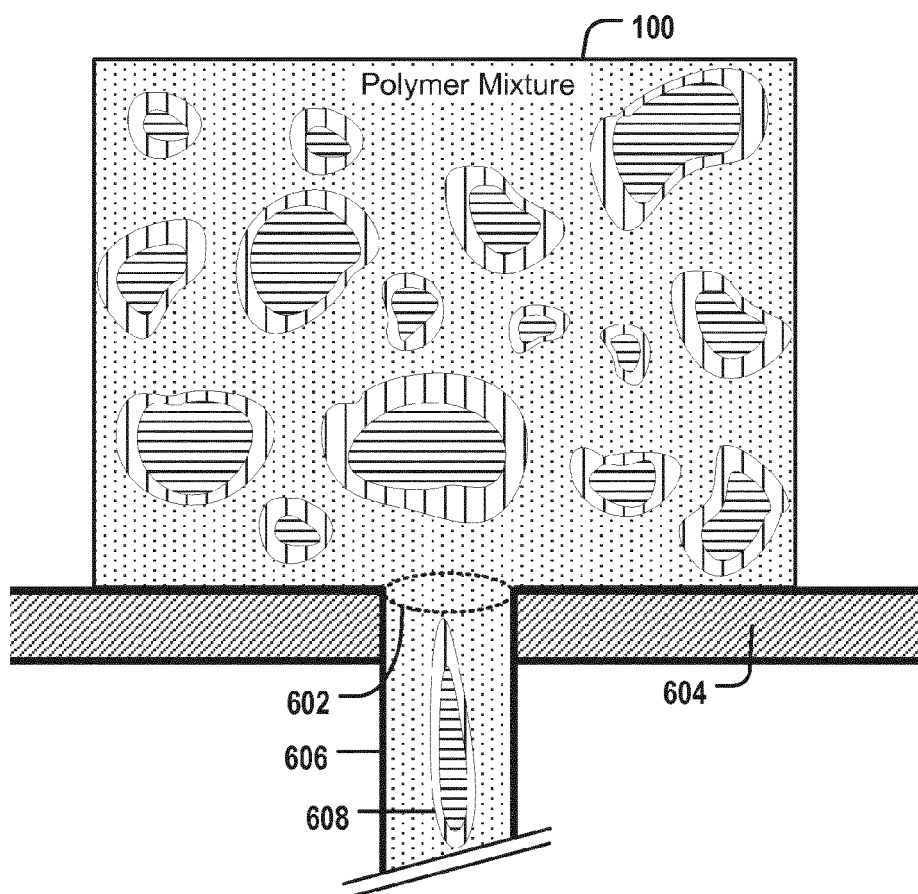


Fig. 6

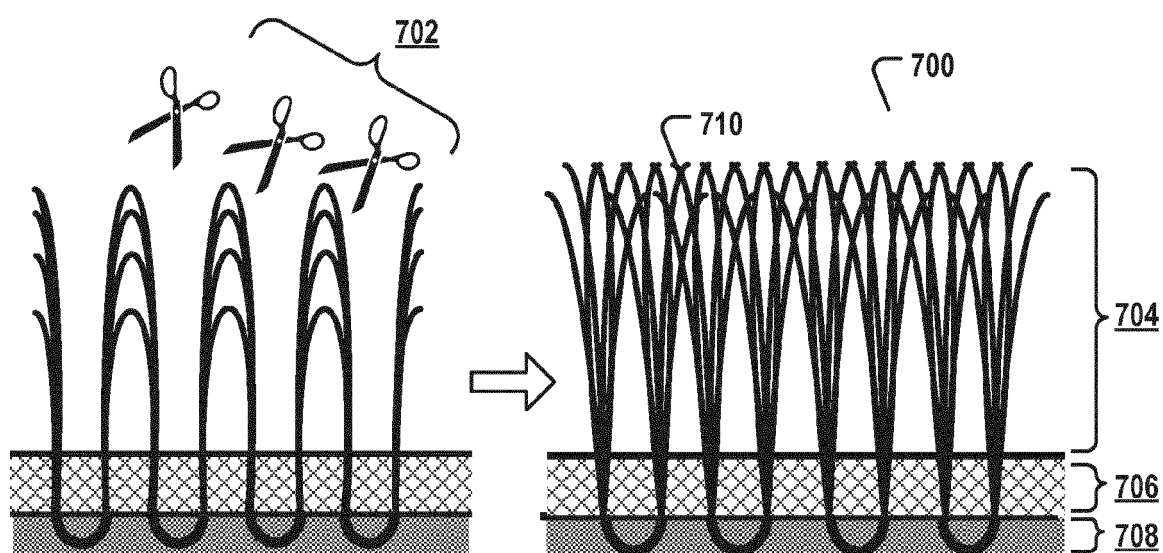


Fig. 7A

Fig. 7B

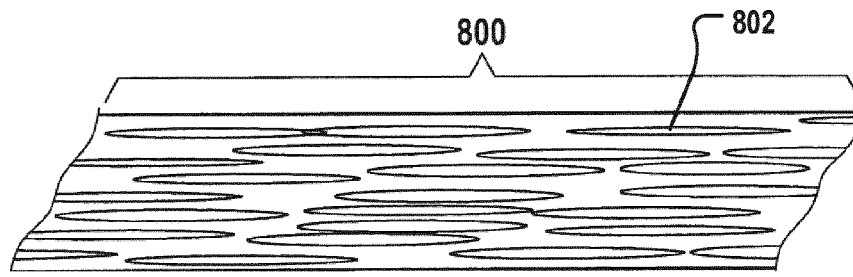


Fig. 8A

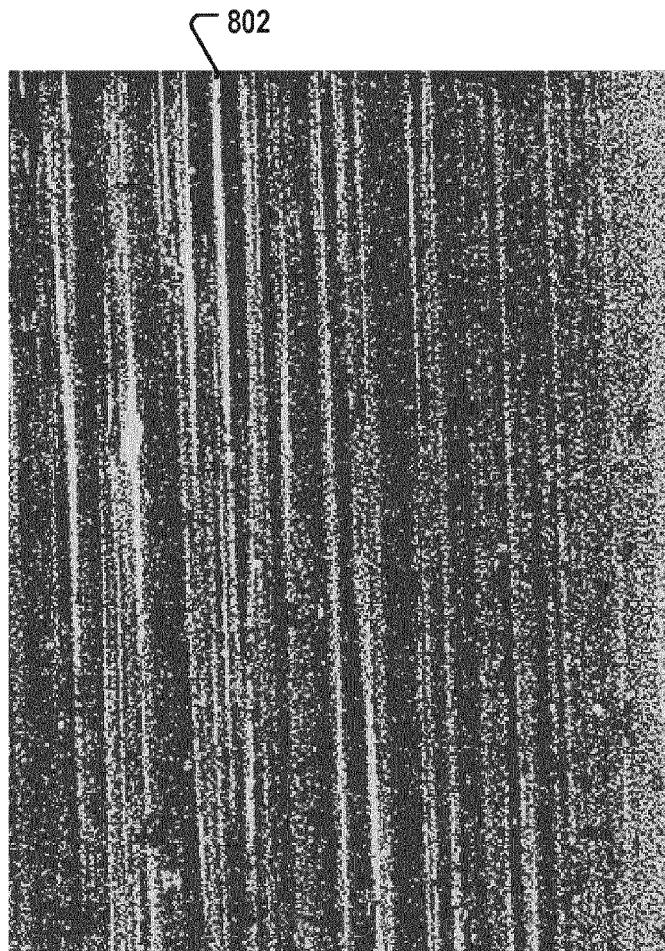


Fig. 8B

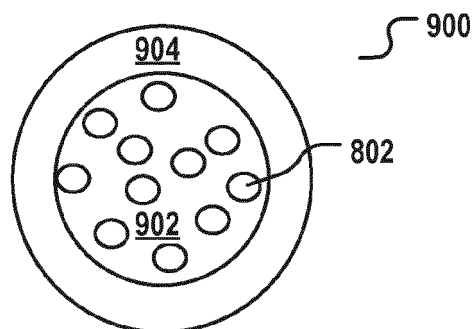


Fig. 9A

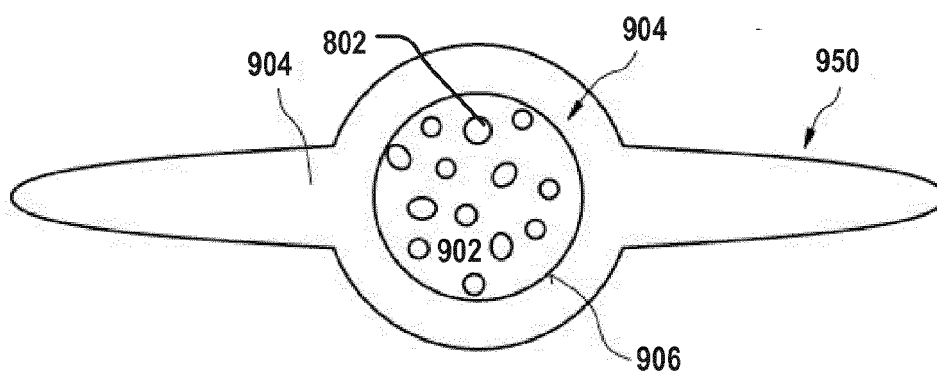


Fig. 9B

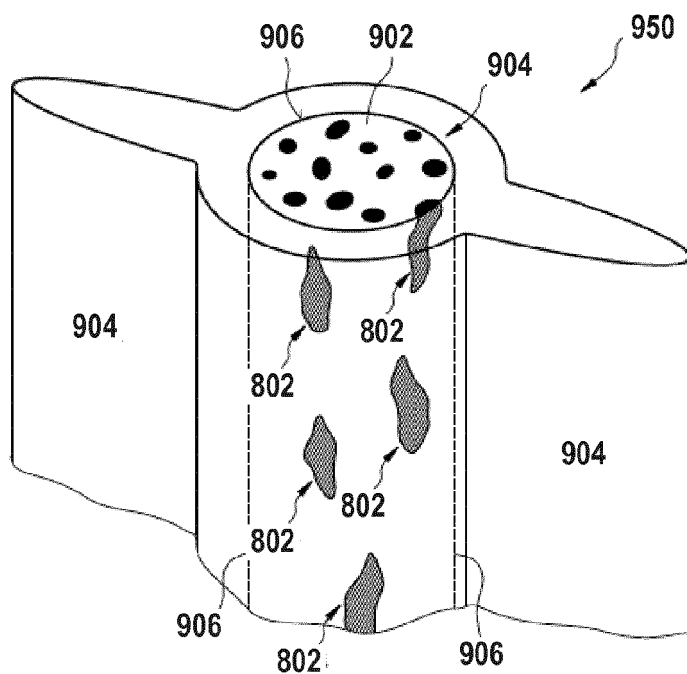


Fig. 9C

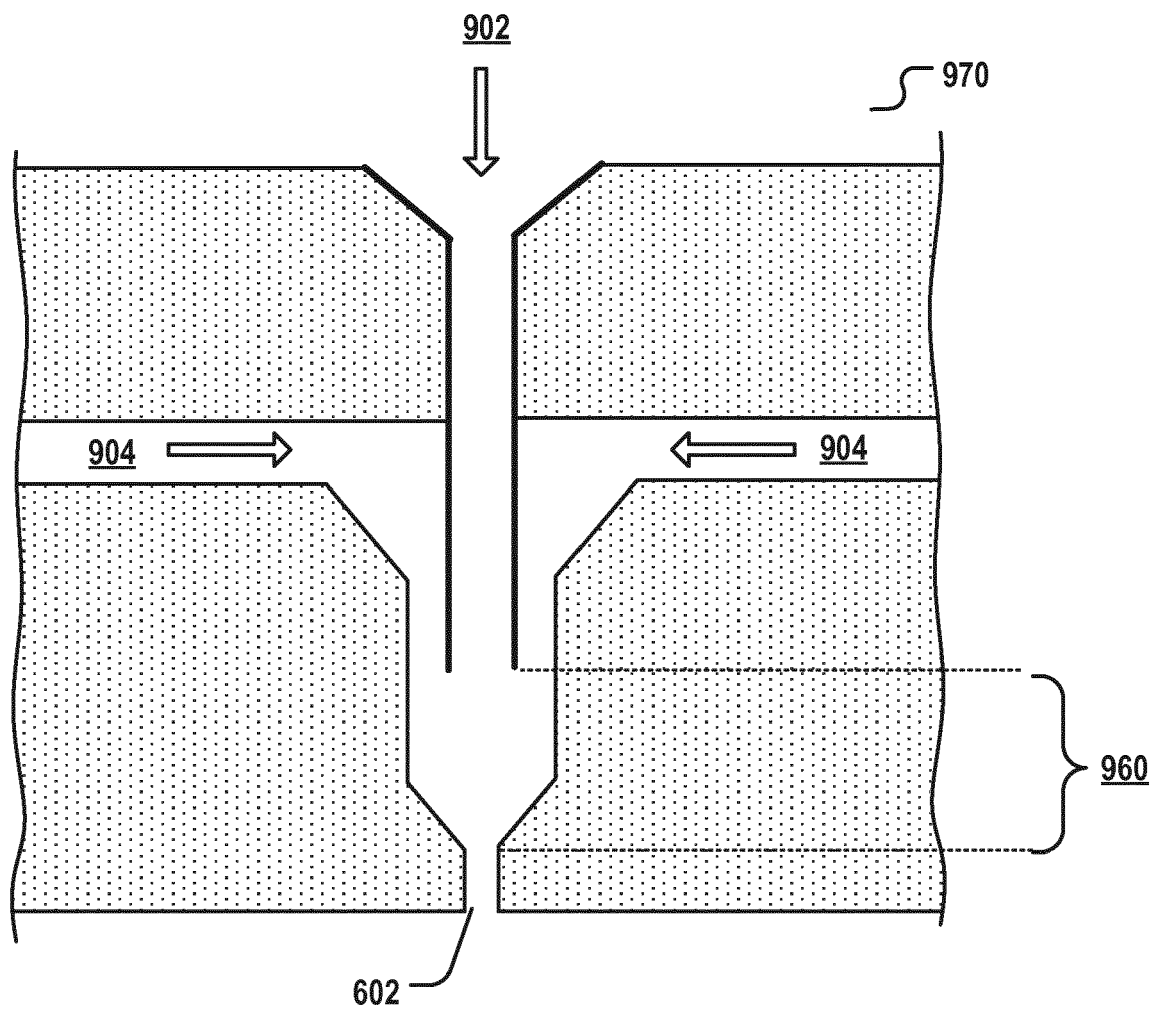


Fig. 10



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EP 18 18 6326

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Place of search The Hague		Date of completion of the search 23 November 2018	Examiner Verschuren, Jo
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